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Utilizing Marine Life Resources

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Sea as New Technology Frontier Examined

43063546A Tokyo JAPAN SCIENCE AND TECHNOLOGY in Japanese Feb-Apr 89 pp 60-65

[Article by Isao Karube, Leading-Edge Science and Technology Center, University of Tokyo]

[Text] Leading-edge science and technology are essential to progress in marine biology. Leading-edge scientific and technological systems are indispensable to the monitoring of the sea, the study and collection of marine organisms, various testing and other activities, energy production, and the management of "sea pastures." Utilizing these support technologies to full advantage, researchers are setting out to deploy new developments in marine biology.

Biotechnology involving marine organisms has suddenly become the focus of considerable attention. There are several reasons for this. One is that as biotechnology has developed, the scope of its applications has expanded from microorganisms to higher animals, and interest has shifted from terrestrial to marine organisms. Another is that the field of marine biology is the most appropriate area for the expansion of the machinery, building, and other industries that have not shared in the biotechnology boom from the beginning. That is, every conceivable type of science and technology, including that pertaining to man-made satellites, ships, construction, specialized equipment, and electric communications systems, must be used to expand marine biotechnology, so these industries will benefit from participating in this expansion. The most compelling reason is that the sea is virgin territory, and the development of completely new biotechnologies is expected to result from learning about the organisms that live in it and from exploiting their functions. The sea is so alluring that it has become the center of attention. Of course, various government projects are certain to give impetus to this boom in marine biotechnology. These projects include the "Research Center for the Industrial Utilization of Marine Organisms" project most recently initiated by the Ministry of International Trade and Industry; the "Marine Forum" project of the Ministry of Agriculture, Forestry and Fishery; and the "Shinkai 6500" project. Marine biotechnological development of this sort requires that leading-edge science and technology be utilized to the fullest. This report presents the leading-edge scientific and technological systems that support marine biotechnology, and the latest developments in these systems.

Sea Monitoring Systems

The primary focus of the development of marine biotechnology is the vast expanse of the sea, so systems of monitoring the sea, both macroscopically and microscopically, are given priority. The sea covers approximately 70 percent of the earth's surface, and man-made satellites carrying highly efficient sensors are used to monitor it macroscopically. For example, the U.S. Scripps Institute of Oceanography, University of California, San Diego, obtains information from four man-made satellites, thereby measuring such things as ocean chlorophyll levels and water temperatures. In Japan, the University ofTokyo Oceanographic Research Institute and Tokai University are conducting similar studies. These man-made satellites carry various highly efficient sensors, such as image sensors and infrared sensors (Figure 1). Sea monitoring by these man-made satellites plays an important role in such activities as marine farming and fishing, and is indispensable to environmental monitoring on a global scale.

Other monitoring systems that are used include television cameras and various types of sensors. By fully utilizing the most advanced electronic technology, these systems are capable of monitoring vast areas of the sea. However, systems that are used in terrestrial monitoring cannot be adapted directly to sea monitoring because the sea is subject to violent weather changes, and the salt in seawater can damage equipment. Therefore, rather specialized sea monitoring systems must be developed to support marine biotechnology.

Systems for Studying and Collecting Marine Organisms

The subject of marine biotechnology is marine organisms. The term "marine organisms" is a broad term covering microorganisms, seaweeds, invertebrates, and vertebrates. The fact that the sea has an average depth of 3,800 m, an average atmospheric pressure of 380 atm, and temperatures below 5)studying marine organisms. Special research ships, submarines, aircraft, and collecting apparatus are essential for studying and collecting organisms that live in such a specialized environment. Marine research ships (Photo 1 [not reproduced]) are fitted with various types of research apparatus that were developed by fully exploiting leading-edge technologies, and have laboratories equipped with a variety of analytical devices on board. With these, investigators can perform diverse tasks, from observing marine atmospheric phenomena to analyzing seawater. Some of these research ships also are equipped with automatic submarines that investigate the sea floor. Investigators at the Woods Hole Oceanographic Institution (Massachusetts) are using pilotless submarines to survey the oceans of the world on a large scale.

In Japan, the Marine Science and Technology Center of the Science and Technology Agency has been surveying Japan's coastal waters using the Shinkai 2000 submarine, and this work is yielding substantial research results. In addition, using these results, they are perfecting and testing the Shinkai 6500. Since these will be discussed later, no more will be said about them here.

Special apparatus is needed for collecting marine organisms. It is particularly difficult to collect deep-sea organisms and then transport them over sea or land while keeping them under the environmental conditions of the deep sea. Workers at such facilities as the Woods Hole Oceanographic Institution and the Scripps Institute of

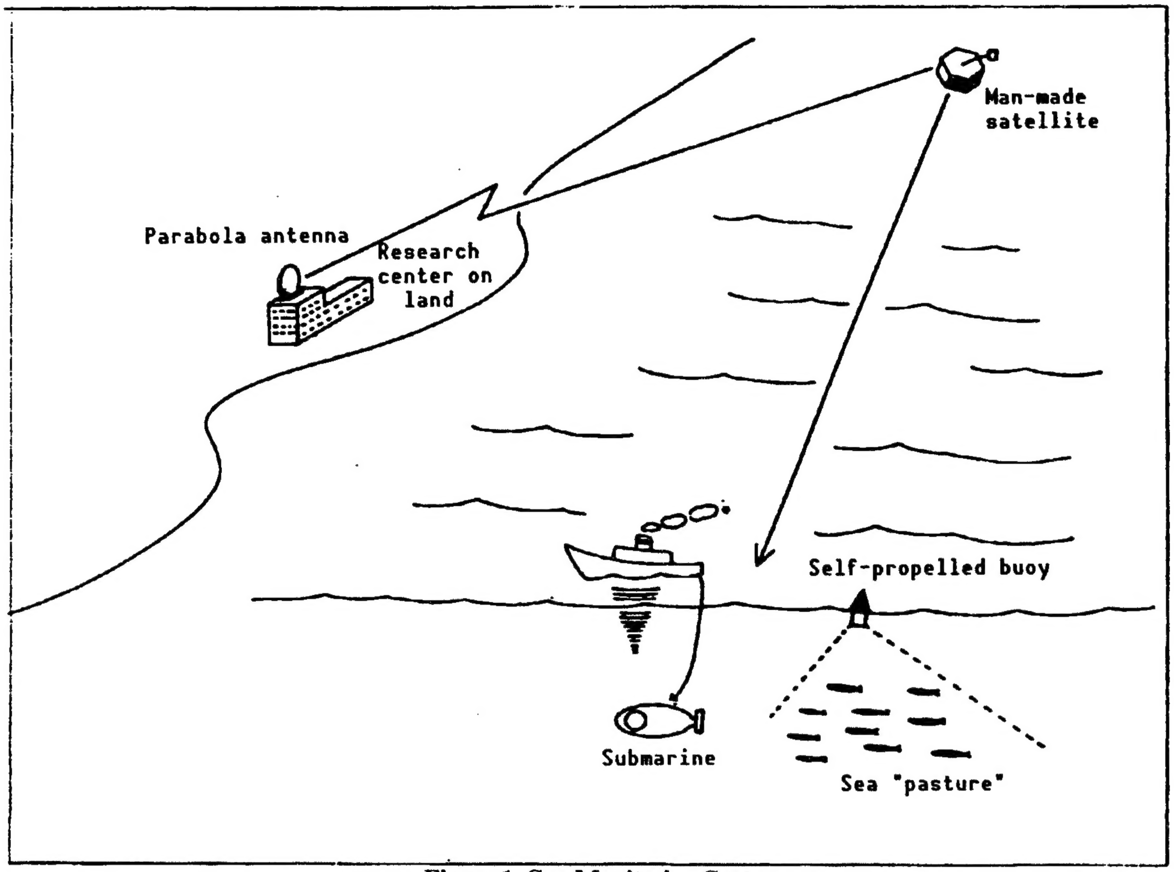

Figure 1. Sea Monitoring System

Key: A system for macroscopically and microscopically monitoring vast areas of the sea has become essential. Man-made satellites carry highly efficient sensors, such as image sensors and ultraviolet ray sensors. Monitoring the sea by man-made satellite plays an important role in such activities as managing sea "pastures," and fishing.

Oceanography have developed devices for collecting deep-sea organisms and seawater that are capable of keeping those organisms and water samples at deep-sea pressures and temperatures while transporting them to the research ship. In Japan as well, the deep-sea water collector shown in Figure 2 is being developed by the Science and Technology Agency. It is possible tocollect microorganisms, invertebrates, and small fish using these special apparatuses, but difficult to collect larger fish and other organisms. It may be preferable to employ a submarine to collect the larger organisms.

Marine Organisms Testing Systems

Biotechnology can be used to breed and raise marine organisms and clarify how they function in laboratories on land. However, this cannot be done without duplicating in these laboratories the natural environmental conditions of the sea. The "aquatron" is a device that can do this. A dark, high-pressure, low-temperature environment must be created to duplicate the deep-sea environment. Current leading-edge technologies will have to be used to develop the aquatron.

It is highly likely that microorganisms that produce effective physiologically active substances can be collected from the deep sea. However, although microorganisms actually have been collected from the deep sea, it has been difficult to culture them. Deep-sea microorganisms die when they are kept at atmospheric pressure. Consequently, apparatuses in which these microorganisms can be cultured at high pressures and low temperatures must be developed. Culturing these deep- sea microorganisms in large quantities probably will require even larger culture apparatuses. Furthermore, devices capable of automatically screening for physiologically active substances, and systems for automatically growing and maintaining these microorganisms, among other things, must be developed before it will be possible to screen these microorganisms to determine which ones will be useful. For this reason, automated systems, robots and other devices that are currently needed for promoting biotechnology in the laboratory probably will become even more important in the future.

After a microorganism that produces a biologically active substance has been cultured in large quantities,

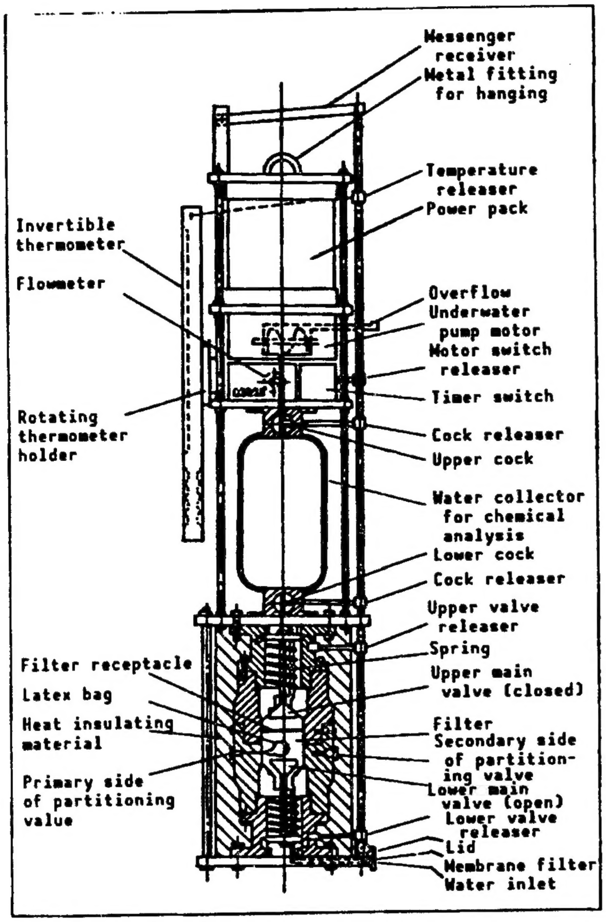

Figure 2. Cross-Sectional View of a High-Pressure, Sterile Water Collector for Collecting Deep-Sea Microorganisms

Key: An apparatus with which it is possible to transport organisms and seawater from the deep sea to the surface or to land while keeping the specimens at deep-sea pressures and temperatures. With these specialized devices it is possible to collect microorganisms, invertebrates, small fish, and other organisms.

the biologically active substance must be extracted from the large volume of culture medium containing it, and then refined. Isolating and refining techniques employing chromatography and membranes can be used for this. Culture mediums with artificial seawater as their substrate contain sodium chloride. The process used to refine the target substance in these culture mediums must be designed with this in mind. The main idea is to concentrate the physiologically active substance in a membrane reactor, and then isolate it by affinity chromatography or a similar technique.

'Sea Pastures' and Their Support Systems

Various support technologies are essential to the spawning and rearing of fish using biotechnology, as well as to the maintenance and management of "sea pastures," specific areas of the sea in which these fish are cultivated. Unlike conventional fish cultivation, the cultivation of fish in sea pastures is done over vast areas of the ocean. Therefore, it requires a wide range of crystal lattice, from the leading-edge to the conventional. Someday such things as unmanned buoysand acoustical feeding systems that release feed to fish when a special sound is transmitted may be used to manage these pastures. Other devices and sensors, such as sound or light barriers for confining the fish to a specific area, fish counting and classifying sensors for monitoring the types and number of fish living in that specific area, and photosensory systems for the early detection of the growth of red tide, probably will be developed. It is likely that these will be controlled from land-based research centers via man-made satellites.

The most important aspect of managing a sea pasture is making sure the fish have enough to eat. To do this one must solve the problem of how to propagate microorganisms, microscopic algae, and plankton in the area. Solar energy and nutritive salts are indispensable to propagating these foods. Therefore, the development of solar condensers and systems for applying light to the deep sea or sea floor may be crucial to managing sea pastures. It is thought that such things as optical fibers will play an important role in this. Also, it is known that nutritive salts abound in the deep sea, so if it were possible to draw those salts up to a higher level, the problem of making sure the fish have enough to eat would be solved. It would take an enormous amount of energy to do this, so ways of tying this in with the development of systems of generating electricity using ocean temperature differentials and solar utilization systems must be considered. (Energy conversion and production in the sea will be discussed later.) Another effective approach to this might be to circulate the seawater using ocean currents and structures built on the sea floor.

As this indicates, it may be possible to propagate microscopic algae, microorganisms, and plankton using various devices and systems. There is a food chain in the sea. If small fish and invertebrates eat this propagated plankton, eventually the production of larger fish and shellfish will increase. Biotechnology will play an important role in speeding the evolution of this food chain. Transgenic fish and shellfish that mature rapidly, as well as fish and shellfish that are three times larger than normal, are already being studied in the laboratory.

It is known that salmon spawn in fresh water, travel down the river to the sea where they mature, and then return to the same river to reproduce. It is thought that young salmon remember the characteristic odor of the river down which they travel and depend on this memory to travel back up the same river; however, while they are at sea, they migrate by sensing terrestrial magnetism. It is thought that this is controlled genetically. Consequently, if the gene controlling this could be pinpointed, it might be possible to clone this gene in other types of fish, such as the tuna, and produce tuna that

migrate only within a specific area. The reason for doing this would be to obtain fish suitable for cultivating in sea pastures. It is thought that in the sea pastures of the future, no nets will be used, instead, the fish will be confined within barriers erected using various electronic techniques or, mentioned above, specific genes will be used.

Structures of the Sea

Various structures may be required to facilitate work in the sea. For example, it is thought that everything from residential research facilities to factories will be constructed in buildings in the shape of platforms on the surface of the ocean, and that they will be designed so as to have heliports and boat docks. Moreover, these structures probably will include facilities for descending from the platform to the sea floor, and it will probably be possible to supervise sea pastures from them. Also, techniques for constructing buildings below the sea surface and on the sea floor will probably be developed. The sea floor is a stable space because, although the temperature on the sea floor is low,it does not fluctuate. However, the atmospheric pressure increases in the sea at the rate of one atmosphere per 10 m from the ocean surface, so structures built on the sea floor must be pressure resistant. Structures built on the ocean surface and on the sea floor probably will not be fixed structures, but will be mobile, so it is likely that they will be called "marine space colonies." Other structures likely to be constructed include structures for raising nutrient salts from the sea floor, and manmade shelters to enable fish and shellfish to increase their production. Building techniques used for terrestrial structures probably will have to be improved to adapt them to building structures in the sea.

Energy Production in the Sea

The most important problem that must be solved before man can live and work in the sea is how to supply the energy needed for these activities. The principal sources of energy, of course, are petroleum and nuclear power, but in order to keep the consumption of energy from these sources to a minimum, it is essential that various types of energy be used efficiently. Various ways of doing this are being studied. For example, ways of producing electricity using the energy of the waves, called "wave energy electricity generation," is being studied. One such system being investigated involves compressing air with wave energy and using this compressed air to rotate turbines. Another important area of research and development is the use of solar energy. A broad range of solar energy utilization techniques, from the production of electricity using solar heat to solar batteries, is being studied.

On the other hand, it is well known that diatoms and green algae (*Chlorophyceae*) produce hydrocarbons. If it were possible to cultivate these algae on a large scale, it would be possible to produce liquid-fuel hydrocarbons from them.

In addition, a project aimed at using giant kelp is in progress in the United States (Figure 3). This giant kelp grows at the rate of one foot a day, so it is a promising resource as a biomass. In this advanced utilization program, materials such as sodium alginate will be extracted from the giant kelp. Furthermore, a process of subjecting the residue to methane fermentation to produce methane gas is being developed. Methane gas is the principal ingredient of municipal gas, and can be used as a gaseous fuel. Also, it is known that some of the blue-green algae (Cyanophyceae) produce hydrogen via the nitrogenase system. It is possible to produce hydrogen by culturing blue-green algae on a large scale. The only by-product of the burning of hydrogen is water, so hydrogen has been attracting considerable attention as a clean energy source. Hydrogen can be converted easily into electric energy by passing it through a fuel cell (Figure 4).

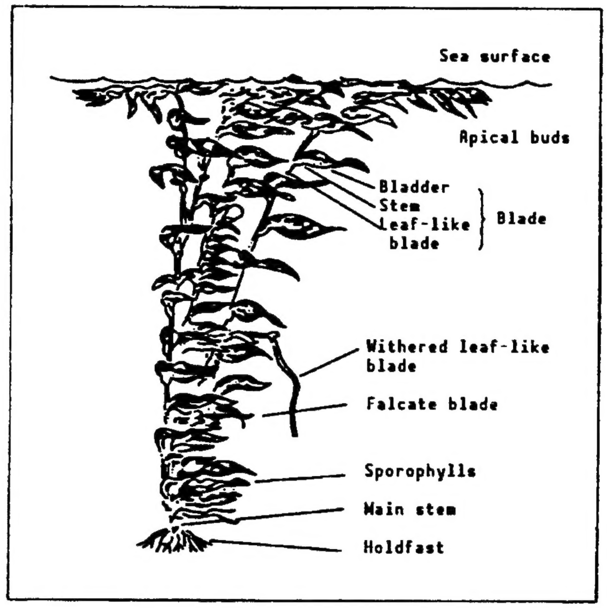

Figure 3. Mature Giant Kelp

Key: This giant kelp grows one foot a day, so it is a promising resource as a biomass. A process of extracting sodium alginate and other materials from giant kelp, and then subjecting the residue to methane fermentation to produce methane gas is being developed. (P.L. Haaker, "Giant Kelp," Marine Resources Leaflet 9, 1955, State of California.)

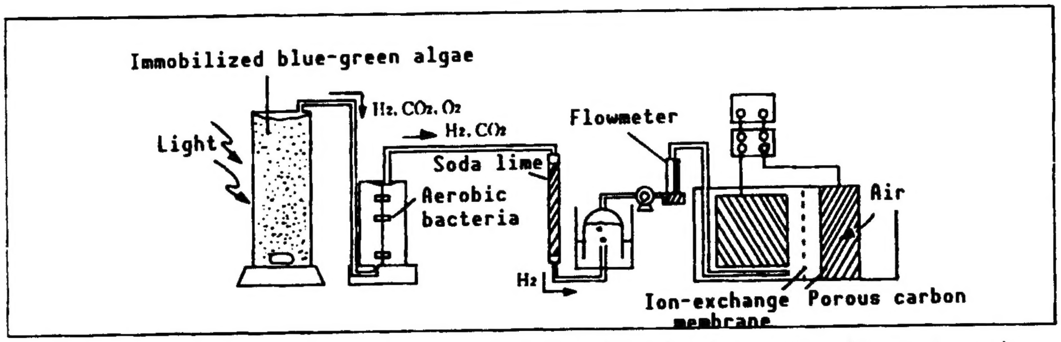

Figure 4. Photochemical Fuel Cell Using Immobilized Blue-Green Algae (Cyanophyceae)

Key: Some blue-green algae produce hydrogen via the nitrogenasesystem. It is possible to convert this hydrogen easily into electric energy by passing it through a fuel cell.

As the preceding discussion indicates, various methods of energy production utilizing the sea are being attempted. It is thought that the consumption of petrochemical fuels such as petroleum and nuclear energy fuel can be drastically reduced through the diversified utilization of these methods.

The Expansion of Marine Biotechnology

Now that I have covered the technologies needed to support the progress of marine biotechnology, I would like to move on to the new fields of research that might be opened by marine biotechnology. Marine biotechnology is a field to which the introduction of various leading- edge scientific technologies is indispensable, and one might say that it is an appropriate biotechnology for Japan. On the other hand, research on marine organisms reveals that they have various superior functions not found in terrestrial organisms. It is thought that a completely new biotechnology can be developed by clarifying these functions and finding practical applications for them.

Researchers in the field of bioelectronics, which was created by fusing biotechnology and electronics, are making great strides in the development of biosensors. For example, they are utilizing enzymes of deep-sea microorganisms that are active at high pressures and low temperatures to increase the efficiency of biosensors. At low temperatures, conventional biosensors produce hardly any output and cannot be used to make measurements. However, by using the enzymes of deep-sea marine observation satellites as the molecular identification element, it may be possible for the first time to manufacture enzymatic sensors that operate at low temperatures. Furthermore, it may be possible to use marine microorganisms themselves as the sensory elements. In addition, it may be possible to improve the durability of biosensors by using the enzymes produced in seawater, since it is thought that these enzymes are more stable than those produced by terrestrial microorganisms. Another field of research that is regarded as being opened by marine biotechnology involves applications of the nervous systems of marine invertebrates. For example, it is thought that clarifying how information is processed by marine invertebrates, which have relatively simple nervous systems, will provide important basic data for the development of neurocomputers with new algorithms and architectures. Researchers are already conducting significant research on the nervous system of the *Aplysia kurodai* (a sea hare). Furthermore, investigators are producing fascinating elements from microorganisms that live in special sea environments. For example, they are using the bacteriorhodopsin produced by *Halobacterium- halobium*, which is an extremely halophilic bacterium, to invent new devices, and they may be able to create a biochip that has as its component an artificial biological element with functions similar to those of bacteriorhodopsin.

Even though the deep-sea environment is one of high hydraulic pressure and low temperature, organisms live quite comfortable in it. It is no dream to think that the study of the mechanisms and functions of the biological elements by which these organisms tolerate high pressures will eventually lead to the production of completely novel pressure-resistant construction equipment, robots, bioactuators, and motors. The elucidation of the function of the gills of fish and shellfish may provide important data for the development of novel artificial gills. The various functions that operate at the cell membrane level may serve as a source of ideas for the development of such novel engineeringsystems as materials transport systems, desalination systems, energy production systems, and information exchange and communications systems.

Marine Biotechnology Problems

While our expectations for marine biotechnology are great, there are many problems that must be solved before these expectations can be fulfilled. For example, the sea is an unknown territory about which we have little knowledge. For this reason, basic research on marine life is extremely important. Also, society will rely heavily on biotechnology or try to arrest the spreading pollution of the marine environment. Any positive

progress in arresting this pollution will require international cooperation. For example, in order to prevent the greenhouse effect, in which carbon dioxide gas rises into the atmosphere, it will be necessary to increase the absorption of carbon dioxide gas by the sea by increasing the production of algae and coral. Such a massive project can only be carried out through international cooperation.

On the other hand, researchers involved in the breeding of transgenic fish and other fish and shellfish should probably proceed slowly, while providing public access to research data. It is important not to ignore ethical questions about life while pursuing this research.

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Industrial Utilization of Marine Organism Resources

43063546B Tokyo JAPAN SCIENCE AND TECHNOLOGY in Japanese Feb-Apr 89 pp 66-73

[Article by Kaname Anjo, research and development officer, General Affairs Division, Agency of Industrial Science and Technology, Ministry of International Trade and Industry]

[Text] Japan, which has the most productive fishing industry in the world, has an obligation to open the way to the positive utilization of the abundant resources of the sea. The research and development of ways to effectively use marine organism resources and genetic resources in mining and manufacturing has been initiated. This research and development is expected to give a major impetus to the development of biotechnology, and to create new industrial fields.

The Ministry of International Trade and Industry (MITI) has selected "Methods of manufacturing highly functional chemical products (utilizing marine organisms)" as the new theme of the 1988 Large-Scale Industrial Technology Research and Development Project ("Large-Scale Project") of MITI's Agency of Industrial Science and Technology and, in addition to taking the necessary budgetary action, MITI decided to establish a "Research Center for the Industrial Utilization of Marine Organisms" as part of its effort to equip a base for this research, a task that MITI instituted this year. They have decided to promote the research and development of marine biotechnology through the close coordination of these two projects.

In this paper I would like to give the background and an outline of both of these projects, and to contribute to the reader's understanding of MITI's policies regarding the research and development of marine biotechnology in Japan.

Background

Japan has the second largest gross national product in the world and, with the United States, is at the center of the world's economy. Furthermore, it has the world's sixth largest economically exploitable water area (200 nautical miles). In 30 short years, Japan has successfully recovered from the desolation of World War II and achieved its current prosperity through technologies development strength supported by the importation of technology. Now, turning toward the 21st century, Japan has the responsibility to build, based on its economic potential, which is the second largest in the world, the technologies that will produce new industries through innovative technological development.

Ever since Japan took its first steps toward becoming a modern nation after the Meiji Imperial Restoration, it has manifested its pride in being a country entirely surrounded by the sea by developing the world's foremost shipping and fisheries industries, with the oceans of the world as their staging ground. It is now anticipated that Japan will also achieve brilliant results in the branches of biotechnology that dealwith the sea, which is a new frontier opened by recent reforms in the industrial structure.

Moreover, the Japanese industrial vitality, which has been subjected twice to petroleum crises and has weathered the Showa era, has matured; while the younger Japanese economy improved upon those technologies imported from various Western nations and put them to practical use, the more mature Japanese economy has progressed to the stage of developing original technology, at its own expense, from the basic technology of basic scientific fields, and of supplying top-level practical technology to international markets.

With this industrial maturity, the focus of the Japanese national technological development policy has also shifted toward basic technology.

Since 1965, MITI has been launching "large-scale projects" based on a national project system that intensifies the technological efforts of the Testing Institute of the Agency of Industrial Science and Technology, as well as those of universities and private industries, as a system for efficiently promoting large-scale technological development.

These large-scale projects have been yielding results that have contributed to the expansion of modern industrial technology, including techniques for preventing industrial environmental pollution, sea water desalination techniques, highly efficient jet engines, main-frame computers, pattern recognition techniques, and optical electronic technology. In the past, this large-scale project system was focused primarily on practical techniques such as these, but one of the themes of this project

system is intended to deal with the establishment of a "marine biotechnology," and to have more basic techniques as its subject. This is the theme selected for the 1988 Large-Scale Project.

Even in the explanation given to the financial authorities during budget negotiations, the phrase "basic large-scale project" was applied to this project.

In addition, MITI, in an effort to encourage technology development, decided to undertake the responsibility of equipping public research facilities to engage in research on specific advanced identification technology, a subject with which they had not previously dealt, and they instituted the task of equipping a base for this research.

To this end, they formed the New Energy Development Organization (NEDO) in October 1988 to take on not only the existing task of developing alternatives to petroleum energy sources, but also that of researching and developing industrial technology more broadly. This organization was formed to serve as the executive organ in the private sector for such technological development projects as the large-scale projects, and also to take on the task of promoting international collaborative research as well as that of equipping base facilities for research.

Background of the Research and Development of Marine Biotechnology

The development of the sea involves a variety of problems. One is how to replenish and stabilize the foundation of the international economic society by putting to practical use, in a positive way, the diverse resources of the sea, including the microscopic and other marine organisms, magnesium nodules and other minerals on the ocean floor, petroleum and other energy resources in the sea, and the energy of the sea itself, such as the energy in its waves, tides, and ocean temperature differential. Other problems include how to systematicallyclarify the ocean environment, and how to contribute to the maintenance of the global ecology. It is hoped that Japan will play a leading role in solving these problems.

The sea, which is the source of terrestrial life, is expected to contain biological and genetic resources that are superior to and more varied than those found on land. It is likely that, by clarifying the life systems of these marine organisms and devising ways to use them effectively in mining and manufacturing, such as in the production of fine chemical products, the modern biotechnology frontier can be opened wide and new industries can be created. It is hoped that Japan, the nation with the world's most productive fishing industry, will lead the way to the positive utilization of these marine organism resources.

However, it seems that marine organism resources are currently being treated as something in which only the fishing industry has an interest, and that practically nothing is being done to facilitate the full-scale utilization of these resources by a wider base of industries. Surprisingly, the idea of using any geological resources in industry is relatively new. It has only been within the past few decades that it has been possible to build upon conventional brewing technology and develop the new biological techniques, such as genetic recombination and cell fusion, into industrially usable techniques. In addition, the organisms that are being used industrially are primarily organisms that live on land or in terrestrial waters. No marine organisms except the products of the fishing industry are being harvested aggressively. This is because, while it is relatively easy to gain access to terrestrial organisms, marine organisms are spread out in three directions over a vast area of water, so marine ecology is not yet fully understood.

Actually, the environments in which marine organisms live differ from terrestrial environments in many ways. For one thing, they are saltwater environments. In addition, their pressure can vary from one to several hundred atmospheres, depending on how far they are from the sea surface. Other factors, such as the amount of light, the oxygen concentration, and the nutrient salt concentration in these marine environments, vary with their depth. Therefore, specialized apparatuses are needed to collect, preserve, and culture organisms from these marine environments. Moreover, biotechnologies developed for terrestrial organisms have to be modified before they can be used for marine organisms. New versions of such research techniques as culture methods, genetic recombination techniques, and cell fusion techniques must be established for use in high-pressure saltwater environments. In addition, broad, long-range basic research is needed in order to conduct an extensive search for a wide variety of organisms, screen them, discover specific organisms and microorganisms that produce useful substances or have useful functions, and develop them to the point where they can be used industrially. Full-scale research of this sort requires that mobile marine research facilities be constructed and equipped, and that marine organisms be subjected to a variety of tests while being bred and preserved under appropriate conditions.

Against this background, since 1988, MITI's Agency of Industrial Science and Technology has been dealing with the following subjects: the adaptation of biotechnology to marine organisms, research and development aimed at the industrial utilization of marine organisms, and policies to support these undertakings.

The Large-Scale Projects

The support being given to marine biotechnology research and development by the Agency of Industrial Science and Technology can be divided broadly into two categories: one is research and development under thelarge-scale project system, and the other is the equipping of the Research Center for the Industrial Utilization of Marine Organisms, a base facility for research.

In 1988, MITI decided to initiate "research and development pertaining to methods of manufacturing highly

functional chemical products (utilizing marine organisms)" as the new theme of the large-scale project of the Agency of Industrial Science and Technology (Figure 1). MITI decided to establish a foundation for the new industrial technologies that are based on the novel biotechnologies that originate from marine organisms. They decided to do this by deploying, in a coordinated way, both the research and development conducted at the National Testing Institute and the studies commissioned by NEDO and conducted by private research facilities.

Table 1. Members of the Marine Chemical Subcommittee of the Sectional Meeting on Large-Scale Technology Development of the Industrial Technology Council

Professor Isao Karube (Chair)	Leading-Edge Science and Technology Center, the University of Tokyo
Associate Professor A. Uchida	Agriculture Department, Kyoto University
Professor S. Kato, director	New Energy Development Organization
Professor H. Kawauchi	Department of Fisheries, Kitasato University
Professor Y. Sugimori	Oceanography Department, Tokai University
O. Suzuki, director	Fine Chemicals Department, Chemical Technology Institute
S. Shiraki, director	Functional Development Department,Microorganisms Industrial Technology Institute
Professor O. Nakayama	Engineering Department, Yamanashi University
Associate Professor S. Fushitani	Agriculture Department, University of Tokyo
E. Furudate, assistant director	Economics Section, Sankei Newspaper
H. Horida, director	Deep-Sea Research Department, Marine Sciences Technology Center
Associate Professor S. Matsunaga	Engineering Department, Tokyo University of Agriculture and Technology
Professor T. Mori	Engineering Department, Keio University
Professor K. Yasumoto	Agriculture Department, Tohoku University
Associate Professor M. Yamaguchi	Agriculture Department, University of Tokyo
Professor H. Yamazaki	Oceanography Department, Tokai University

This research and development is being undertaken with an eye to the diversity of marine organism resources for the purpose of planning for the creation of new industrial fields. It is also being undertaken to study and develop the new biotechnologies that will become the basis of these fields, and to establish the necessary techniques for using marine organisms to produce useful substances, for exploiting the various biological functions of marine organisms, and for other such endeavors.

The basic plan for this research and development was prepared by the Marine Chemical Subcommittee. This subcommittee was established in the summer of 1988 at the "Sectional Meeting on Large-Scale Technology Development" of the Industrial Technology Council, which is an advisory organ of the Ministry of International Trade and Industry. (Subcommittee chair: Isao Karube, professor, Leading-Edge Science and Technology Center, the University of Tokyo. For other members, see Table 1.) The subcommittee had conducted an investigation and prepared a concrete basic plan by November of that year, and on 5 December, MITI approved it.

1. The basic plan for research and development

The following is an outline of the contents of the basic plan for this research and development.

(1) Research and development period

The research and development period is 9 years, starting in 1988. The preliminary research period is to be 1 year and 3 months, from the fourth quarter of 1988 to the end of 1989. Next, in 1990, the Research Center for the Industrial Utilization of Marine Organisms (to be explained later) will be completed and will begin operations. At that point, full-scale research will begin. The essential research will be conducted in the 4 years from 1990 to 1993, with an interim assessment made in the latter half of 1993. The period from 1994 to 1996 is to be the intensive research and development period (Figure 2).

Total research and development cost

This will be approximately ¥15 billion.

Research and development goals and methods

1) Attention will be turned to the diversity of marine organism resources. The utilization of these varied and plentiful resources of marine organisms, from monocellular microorganisms to multicellular higher organisms, will be promoted, and the creation of new industrial fields will be planned. The new biotechnologies that will provide the foundation for these activities will be researched and developed, and techniques such as those needed to produce highly functional chemicals and other useful substances utilizing marine organisms, as well as those needed to utilize the diverse biological functions of marine organisms, will be established.

2) The following research and development will be conducted to achieve these goals.

(1) Establishment of techniques for collecting, isolating, culturing, preserving, breeding, and improving marine organisms as the basic techniques for utilizing marine organisms

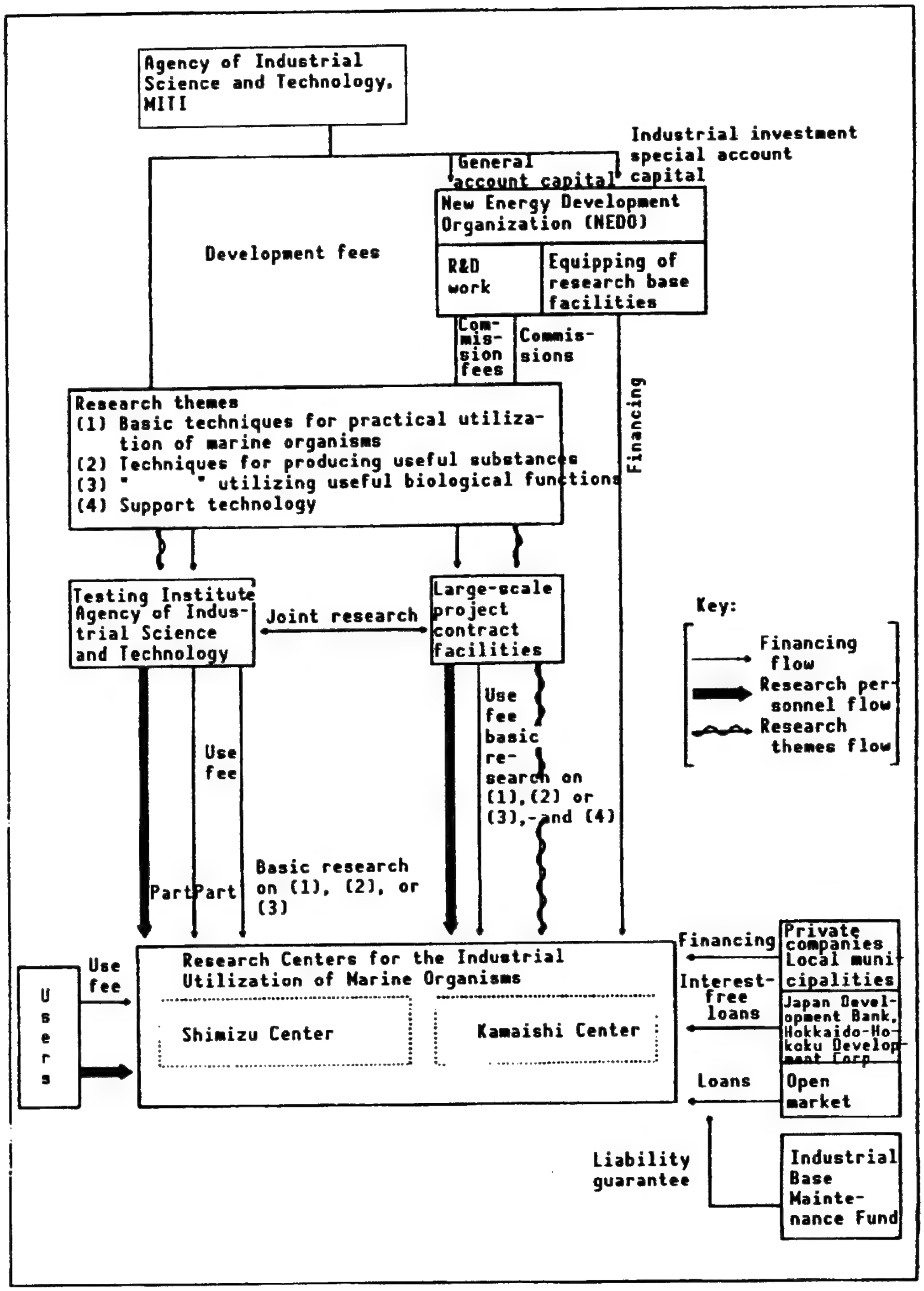
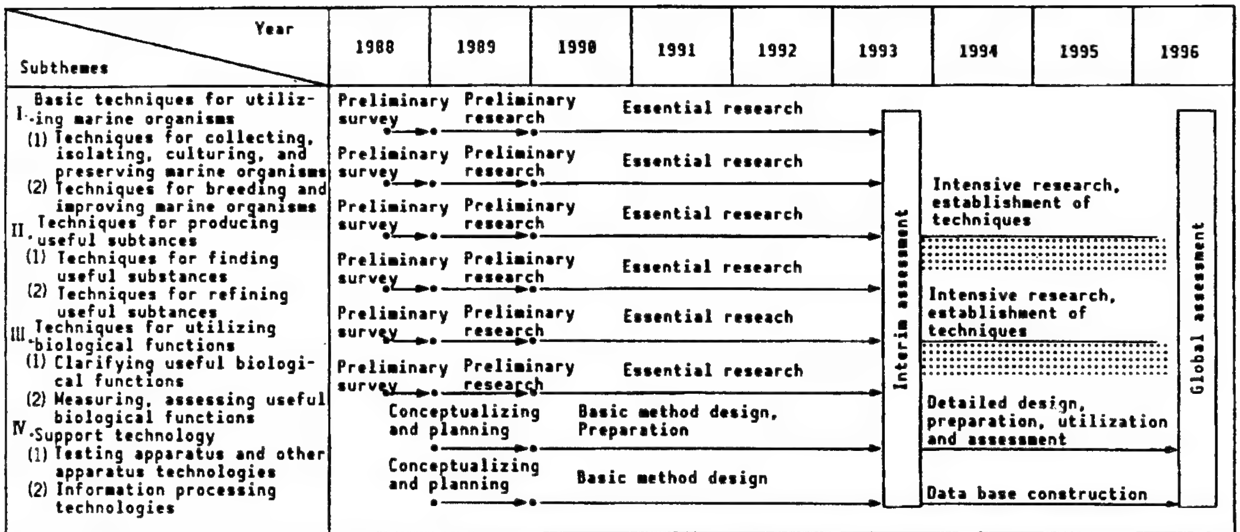


Figure 1. System for Research and Development of Methods of Manufacturing Highly Functional Chemical Products (Utilizing marine organisms)

Key: In 1988, MITI initiated "methods of manufacturing highly functional chemical products (utilizing marine organisms)" as the new theme of the Large-Scale Project of the Agency of Industrial Science and Technology. Research and development on this performed at the National Testing Institute will be developed comprehensively, with the research performed by private research facilities under commission from NEDO.



Budget (million yen)	1988	1989	1990–1996
R&D costs (for Testing Institute, Agency of Industrial Science and Tech.), etc.	7	90	Y15,000,000,000
Investment in NEDO (for research commissioned to private facilities, etc.)	12	184	
Total	19	275	

	1988	1989	1990
Industrial Investment Special Committee total investment (per center) (NEDO's investment in Research Center for Industrial Utilization of Marine Organisms)	700	(700)	(600)
		2000	

Figure 2. Schedule for Research and Development of Marine Chemicals

Key: This was started in the fourth quarter of 1989. The preliminary period will last 1 year and 3 months, to the end of 1989. Then, the essential research will be conducted for 4 years, ending in 1993, and the interim assessment will be conducted in the latter half of 1993. The period from 1984 to 1996 will serve as the intensive research and development period.

(i) Techniques for collecting, isolating, culturing, and preserving marine organisms

- Techniques for collecting, isolating, and culturing marine observation satellite, microscopic algae, etc.
- Techniques for preserving marine microorganisms, microscopic algae, etc. (including preserving their biological activities and building culture collections)
- Techniques for culturing the tissues of multicellular marine organisms

(ii) Technologies for breeding and improving marine organisms

- Techniques for breeding and improving marine observation satellite and microscopic algae, and the cell systems of multicellular marine organisms such as the introduction of characteristics and genetic manipulation (including cell fusion techniques and such genetic recombination techniques as host-vector system development)
- Marine organism gene library techniques

(2) The development of techniques for finding, refining, and otherwise handling useful substances from marine organisms, for the purpose of producing highly functional chemical products

(i) Techniques for finding useful substances

- Search techniques for discovering the utility of substances, for example, as dyes, antioxidants, adhesives, surfactants, information- communicating substances, biological adhesion inhibitors, and growth suppressants (including large-volume culture techniques for finding substances that are present only in minute amounts)

(ii) Techniques for refining, etc., useful substances

- Techniques for extracting, isolating, and refining useful substances from such sources as the bodies of marine organisms and the media in which marine organisms were cultured, and techniques such as chemical modification for making these substances highly functional.

(3) The development of techniques for finding and clarifying useful biological functions for the purpose of utilizing the biological functions of marine organisms

(i) Techniques for finding and clarifying useful biological functions

- Techniques for finding and clarifying such biological functions as rare metal concentration, sea purification, photosynthesis, the inciting of adhesion or evasion, and chemical conversion.

(ii) Techniques for measuring and assessing useful biological functions

3) Conducting supporting research

(1) Essential apparatus technologies

Testing apparatus technologies will be covered in the research of 2) (1)-(3) as part of the main research and development. However, the following items are considered to be essential apparatus technologies and, for that reason, are being given special mention in this section on supporting research:

- Technologies involved in producing apparatuses that reproduce the natural environmental conditions of the sea (aquatrons)
- Technologies involved in producing apparatuses for culturing organisms in special marine environments
- Large-volume culturing technology
- Collecting apparatus technology

(2) Information processing technologies, etc.

In order to offer the results of this research and development for wide domestic and international use, a public-access data base will be prepared, and provisions will be made to enter in it the information collected in comprehensive surveys and by other means in Japan and other countries.

4) Provisions will be made to use the Research Center for the Industrial Utilization of Marine Organisms for this research and development and efforts will be made to assure that this center is used in a flexible and practical manner by reconsidering, at each stage of the research and development process when necessary, the items being researched and developed. This will first be done as part of the interim assessment.

Research and development system

The research and development will be conducted at the Testing Institute of the Agency of Industrial Science and Technology, and at private laboratories under commission from NEDO.

Six laboratories are part of the Testing Institute of the Agency of Industrial Science and Technology: the Microorganisms Industrial Technology Laboratory (director: C. Suzuki), the Chemical Technology Laboratory (director: H. Yoshidome), the Tohoku Industrial Technology Laboratory (director: M. Ishihara), the Osaka Industrial Technology Laboratory (director: A. Hayami), the Shikoku Industrial Technology Laboratory (director: Y. Takemori), and the Chukoku Industrial Technology Laboratory (director: M. Nakayama). These laboratories are engaged in research aimed at obtaining basic knowledge.

As already mentioned, the New Energy Development Organization (NEDO) was expanded and reorganized in October 1988, and as a result, began to undertake three tasks: the research and development of industrial technology, the equipping of base facilities for research, and the promotion of international collaborative research. Although one of these tasks is called "research and development," there are no researchers in NEDO except in its Monopoly Alcohol Project Division, so they handle this responsibility by contracting the research and development to private companies and others. NEDO itself oversees the research and development.

NEDO advertised the research and development work beginning in mid- December 1988, and this February, it awarded the contract to the MarineBiotechnology Institute Co., Ltd. This is a joint research company established on 21 December 1988, jointly capitalized by 24 companies, including Shin-Nihon Seitetsu Co., Ltd., Toa Nenryo Kogyo, Ltd., Kyowa Hakko Kogyo, Ltd., and Santori, Ltd. (president: Mikio Kato, president of Kyowa Hakko Kogyo, Ltd.; capitalization: ¥800 million). It is a privately established company tailored to this opportunity to promote marine biotechnology research and development. (More about this company will be given later in this paper.)

This company is expected to hire about 60 researchers in a broad range of fields, including microbiology, biology, pharmacology, medicine, and oceanography, and to centralize the research and development, using the Research Center for the Industrial Utilization of Marine Organisms. The preliminary research period will be devoted to preparing for the centralized research that will be conducted at the Center, and this preparation will take the form of joint research with the Testing Institute of the Agency of Industrial Science and Technology at such places as Tsukuba Science City.

Research Center for the Industrial Utilization of Marine Organisms

The Research Center for the Industrial Utilization of Marine Organisms is a base facility for research on marine biotechnology that is being equipped by NEDO.

"Base facilities for research" refers to facilities intended for the research and development of advanced industrial technology that are built on a suitable scale and that are offered for the joint use of many researchers. In Japan, generally speaking, there are no research and development facilities of that size that can be used by many researchers. For this reason, NEDO has begun the task of equipping such facilities by financing this work. NEDO

is authorized to do this by the Law for the Preparation of a System for Researching and Developing Industrial Technology that came into effect in October 1988.

Specifically, a company will be established as a "third sector" by means of financing from NEDO, municipalities, and private industry, and this "third sector" will equip and manage the research facilities.

The Research Center for the Industrial Utilization of Marine Organisms is one of the facilities planned by NEDO as part of their task of equipping base facilities for research (one of the three tasks NEDO was given in 1988. (The others are the Research Center for Subterranean Weightless Environments and the Ion Engineering Center.) The estimated cost of building and equipping this center is ¥6 billion. Of this ¥3 billion will be financed through investments, and ¥3 billion will be borrowed, with ¥2.1 billion, or 70 percent of the ¥3 billion borrowed, loaned interest-free by the Japan Development Bank and the Hokkaido-Tohoku Development Corp.

The research facilities of this center are to be built in two locations, Kamaishi, Iwate Prefecture, and Shimizu, Shizuoka Prefecture, each for ¥3 billion. The funds to cover the building costs will be raised over a 3-year period starting in 1988, but the facilities are scheduled to be open for use in early 1990.

The "third sector" that will be equipping the centers is the Research Center for the Industrial Utilization of Marine Organisms, Ltd. This company was created on 19 January 1989. The companies that are financing the Marine Biotechnology Institute Co. (Kyowa Hakko Kogyo, Ltd., Shin- Nihon Seitetsu Co., Ltd., Toa Nenryo Kogyo, Ltd., etc.) made the actual preliminary arrangements for the Research Center for the Industrial Utilization of Marine Organisms, Ltd., and established this company.Therefore, this company will be financed by those 24 private enterprises and the Marine Biotechnology Institute Co. itself, in addition to NEDO, Iwate Prefecture, Shizuoka Prefecture, and the towns of Kamaishi and Shimizu. Mikio Kato has been named president of this company (Table 2).

Table 2. Outline of the Research Center for the Industrial Utilization of Marine Organisms, Ltd., and the Marine Biotechnology Institute Co., Ltd.

1. Company name	Research Center for Industrial Utilization of Marine Organisms (RIUMO)	Marine Biotechnology Institute Co., Ltd. (MBI)
2. Financing, etc.	Company formed by the third sector	Company formed by 24 private companies
	Authorized capital: ¥3 billion	Authorized capital: ¥3.2 billion
	From NEDO: 2 billion	
	From private and municipal investors: ¥1 billion	
	Capital when established: ¥1.7 billion	Capital when established ¥.8 billion
	From NEDO: ¥.7 billion	From private investors (24): (24 investors) ¥.8 billion
	From private and municipal investors (30): ¥1 billion	
3. Established	January 1989	December 1988
4. Business	(1) Leasing facilities for research on the use of marine organisms in industrial fields	(1) Conducting work under commission and commissioning the work of research and development pertaining to marine biotechnology
	(2) All work incidental and related to the above	(2) On-site approval and marketing of the results of the research and development of marine biotechnology
		(3) Planning and executing training sessions and seminars on marine biotechnology
		(4) Consultant work pertaining to marine biotechnology
		(5) Technical information supply services
		(6) Work incidental to the above
5. (1) Head office address	Hongo Segawa Building, 3rd Floor 35-10 Hongo 2-chome, Bunkyo-ku Tokyo	Hongo Segawa Building, 3rd Floor 35-10 Hongo 2-chome, Bunkyo-ku Tokyo
	Tel: 03-5684-6221; FAX: 03-5684-6220	Tel: 03-5684-6211; FAX: 03-5684-6220
(2) Center locations	Kamaishi, Iwate Prefecture, and Shimizu, Shizuoka Prefecture	
6. 1987-1988 (Business)	(1) Arranging for and initiating the construction of facilities, and ordering equipment and installations	(1) Conducting research under commission and commissioning research; planning joint research themes; and activities pertaining to receiving order goods
	(2) Inspecting and receiving the facilities, equipment and installations	Initiating research activities required for the execution of the Large-Scale Project

Table 2. Outline of the Research Center for the Industrial Utilization of Marine Organisms, Ltd., and the Marine Biotechnology Institute Co., Ltd. (Continued)

		(3) Investigating and planning collaborative international research
7. Other	Anticipated date of facilities' ground-breaking: March 1989	The establishment of a council composed of members of scientific societies that will promote the up-grading of the technical and research standards will be investigated
	Anticipated date that public can begin using equipment: April 1990	Researchers: About 70
	Outline of each center	Handling of results: The results will revert to this company
	(1) Size of site: About 20,000 m^2	
	(2) Area covered by building: about 5,000 m^2	
	(3) ¥3 billion	
	The establishment of a council composed of national and local businesses, universities, and governmental entities that will promote the upgrading of the administration and technical level of the research will be planned	

This company is expected to design the center and then start construction of the research facilities in March 1989.

The research facilities are to be equipped with such things as a raw seawater sampling apparatus, seawater sterilizing equipment, experimental water containers that reproduce oceanic conditions (aquatrons), special culture containers, special collecting apparatuses, and various analytical apparatuses.

These research facilities will be open to researchers in a wide variety of fields, and it is anticipated that basic and leading-edge biotechnology will be developed. Moreover, these research facilities are expected to contribute to international research collaboration because they will be open to researchers from around the world.

Research and Development Activity in the Private Sector

This section will cover work other than that connected with the national projects that is being done to promote the research and development of marine biotechnology.

1. The Marine Biotechnology Society

Since the academic community is also very concerned about marine biotechnology, in September 1987 the Marine Biotechnology Society was formed, with J. Miyachi, director of the Applied Microorganisms Institute, the University of Tokyo, appointed as society president. It is reported that this is an autonomous society that was established for the purpose of offering a forum for the exchange of information and discussions, as well as for cooperative efforts among the industrial, governmental, and academic communities in order to promote the effective utilization of scientific technology in supporting marine research, not only involving the utilization of marine organisms, but also such subjects as construction, electronics, and robotics.

The immediate activities of this society are aimed at doing the following in connection with effectively utilizing marine organisms and developing support systems and technologies: 1) collecting information, 2) keeping the society in operation, 3) promoting industrialization, and 4) promoting international cooperation.

The society has appointed Miyachi as their president, and Y. Okami (assistant director, Microbiological Chemistry Institute), Professor I. Karube (Leading-Edge Science and Technology Center), the University of Tokyo), and K. Nemoto, (director, Oceanography Institute, the University of Tokyo) as their vice presidents.

This society has held three conferences to date. In addition, they are preparing to hold the First International Symposium on marine biotechnology in early September 1989.

2. The Marine Biotechnology Institute Co., Ltd.

The Marine Biotechnology Institute Co., Ltd., is a joint research and development company established on 21 December 1988. It is financed by24 private enterprises (president: Mikio Kato, president of Kyowa Hakko Kogyo, Ltd.).

The enterprises that are financing this company represent a broad range of industries, including petroleum refining, steel, brewing, food, chemical, construction, and shipping. These enterprises formed the Marine Biotechnology Society in September 1987 and, for about 1 year, promoted discussions and investigations of such topics as the technological frontiers and research approaches that could be expected in the research and development of marine biotechnology.

The Marine Biotechnology Institute Co., Ltd. has its own research staff. It is undertaking the following research and development.

- 1. Research on its own research topics.

- 2. Research commissioned by NEDO for the Large-Scale Project of the Agency of Industrial Science and Technology, MITI.
- 3. Research commissioned by Japanese and foreign enterprises, universities, research institutions and other entities, and joint research under contract with these entities.

This company is expected to arrange for its researchers to work at the centers described above and to carry out its primary research activities at those facilities. It will research and develop such technologies as the following: 1) basic technologies for the utilization of marine organisms, 2) technologies for producing useful substances, 3) technologies for the utilization of useful biological functions, and 4) support technologies.

The specific "targets" of this company include techniques for producing such useful substances as novel surfactants, dyes, viscous polysaccharides, and novel coatings; bioreactors; techniques for purifying the sea; and techniques for utilizing useful functions such as concentrating rare metals. This company's studies will focus on organisms that are not currently being utilized as resources to any great extent, such as marine microorganisms, microscopic algae and other algae, protochordata, sponges, and coelentera. They will exploit in full such leading-edge biotechnologies as collecting techniques, preserving techniques, breeding and improving techniques, and culturing, isolating and refining techniques.

3. Attitudes at the Universities

University researchers are engaging in a frank exchange of ideas about marine biotechnology, not only within the Marine Biotechnology Society, but also at meetings of the Marine Chemicals Subcommittee of the Large- Scale Technology Development Sectional Meeting of MITI's Industrial Technology Council.

Furthermore, the universities applied to do the [1988] Large-Scale Project when this was advertised. Almost all of the research conducted for past projects of the Agency of Industrial Science and Technology was applied research, so few universities had been commissioned to do it. However, one can say that this project attracted the attention of universities because some of the research involved in it is basic research.

As it turned out, NEDO did not commission a university directly to conduct research for the 1988 Large-Scale Project, but it is likely that universities will collaborate in advancing this research in the future.

International Collaboration

As mentioned above, the Marine Biotechnology Society is planning an international symposium. In addition, the Japan External Trade Recovery Organization (JETRO) is organizing a Subcommittee on the Promotion of International Collaboration on Marine Biotechnology, and is investigating the possibility of international collaboration as part of its task of promoting the international development of industrial technology.

Extensive oceanographic research is being conducted in the United States at Woods Hole and the University of Maryland. A great deal of international collaborative research is expected in this research and development of marine biotechnology as well.

Already, A.A. Benson (Scripps Institute of Oceanography) and R. Colwell (University of Maryland) have come to Japan from the United States and have held spirited discussions with the Marine Chemicals Subcommittee. Also, an Opinion Exchange Mission from Japan will visit the United States on 7-15 February of this year. This Opinion Exchange Mission will be chaired by Professor Karube of the University of Tokyo and composed of representatives from NEDO, Shizuoka Prefecture, Iwate Prefecture, and the Marine Biotechnology Institute Co.

Forms of international research collaboration include joint research, the exchange of researchers, and the use of research facilities, such as the centers described above, by researchers from other countries. It is anticipated that joint research with Europeans, Americans, Australians, and others will take place in the private sector where opportunities for the research and development of marine biotechnology are increasing, and that researchers from the private sector of other countries will use the centers.

Ministry of Agriculture Project for Expanded Utilization of Marine Life Resources

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[Article by Toshihiko Matsusato, Ministry of Agriculture, Forestry and Fishery]

[Text] For hundreds of years, the sea has supplied Japan with a wide range of marine resources. From food to medicines and even cosmetics, many industries are rooted in the sea. Today, with the intensified utilization of marine resources and the further applications of development to the hitherto untapped area of the ocean floor, there is a growing need for the preparation of new concepts and structures.

To researchers involved with marine fields, particularly the areas of aquaculture and the utilization and processing of marine products, there is something just a little "fishy" about the "marine biotechnology" headlines currently being trumpeted by the media. Japan's earliest recorded history notes the burning of eelgrass to obtain salt. In other words, inorganic salts were being obtained from seaweed. Before World War II, santonin was used against intestinal parasites, cod liver oil was used as a supplementary source of Vitamin D, sardines were eaten to prevent night blindness, and eel was

recommended for summer fatigue. Thus marine products were used not only as foods, but also as sources of medicinal products. Such multipurpose foods have recently been selectively redesignated as "high-performance foods." In addition to their use as foods, marine products have become broadly diversified in application, and include jewelry such as coral and pearls, hygienic products such as sponges, coral cement from coral reefs, fertilizer from Maiwashi herring, fuel oils, and lubricating oils. Whales can be cited as a very clear example of this. In addition to meat and whale oil, whales provide raw materials for cosmetics, medicines, and industrial arts. This is truly an animal which can be utilized completely, without waste. The utilization of such multipurpose marine products naturally must be supported through the considerable diversification of marine product technology. Usage in the area of food products alone has led to an expanded base of technology for the processing, storage, and utilization of marine products in Japan, including, for example, complex technologies ranging from carp and rice sushi to the development of various types of salted products, fermented products such as salt- pickled horse mackerel, and fermented and dried products such as dried bonito. These developments have progressed continually down through the ages, with their implementation being due to popular demand.

Therefore today's headline-making emphasis on "marine biotechnology" appears to marine researchers to be just a poorly done rephrasing of technology developed for the utilization and processing of marine production and aquaculture. It is not only difficult to distinguish "biotechnology" from areas of conventional molecular biology, molecular genetics, and cytology, but designation of the new term "marine biotechnology" may actually cloud the definitions even more. First, the word "marine" indicates a location in the sea. If the intent is toindicate biotechnology concerning sea life, then perhaps the expression should be "marine organism biotechnology." Are we to say that "marine bio" + "biotechnology" = "marine biotechnology?" In that case, the term should not apply to organisms living in large bodies of water on the land, or in water vapor. A term such as "aqua-biotechnology" would be preferable.

In any case, the study of marine organisms, which has been dominated up to this point by physics and marine science, is now attracting attention from other areas, and new methods of utilization are being developed. This is a fine thing, and should result in further fruit from conventional marine production. For example, new technology was recently developed for the use of viscous liquid from kelp in the production of metal thin-film superconductors. However, it has been found that (gagome) is even better for this purpose than kelp, suggesting the possible need for its cultivation. In this manner, when a new way of using a function or product of a marine organism is discovered, it can lead not only to the chemical synthesis or cellular biosynthesis of the active constituent, but also to the propagation of the active constituent itself. Therefore, all oceanic organisms which are useful in industry can be termed "marine organisms." Considered in this light, a general understanding of "marine biotechnology" would mean a reevaluation at the molecular biology level of all of the functions of marine organisms, including all conventional marine organisms, or in other words, the reclassification of oceanic organisms as "marine organisms." For this reason, the "marine biotechnology" approach must include expanding applications of marine organisms as well as those for which no use has yet been found. Below, the authors will explain the contents of marine biotechnology-related projects in various areas of marine studies.

Research Related to Biotechnology of Marine Organisms

1. Marine Viruses

Research on oceanic viruses has, in the past, proceeded from two different directions: bacteriophages and pathogens. The analysis of genetic structures has not yet been initiated. In the area of bacteriophages, research has just begun on the possibility of creating vectors. No specific results have been achieved to date, but research is progressing. A special research project by the Ministry of Agriculture, Forestry and Fishery, entitled "The Analysis of Animal Genetics and Development of Applied Technology (Animal DNA)" is scheduled to begin in 1989 and run until 1994.

Pathogenic viruses are widely seen in marine animals from Flagellata and amoebas up through the larger animals, and research has been conducted in the Baculoviridae in prawn and the Herpes virus in fish. However, to date no investigation has been made at the genetic level. Such research is being pursued through the research department of the Fisheries Agency, under such project titles as "Operational Countermeasures for the Prevention of Epidemics in Fish" and "Developing Technology for the Nurturing of Healthy Seedlings."

2. Marine Bacteria

Broad-based research on marine bacteria has proceeded in a number of areas, including 1) bacteria under special environments; 2) useful bacteria such as nitrogen-fixing bacteria; 3) pathogenic bacteria; 4) bacteria for use in the processing of marine products, such as the (kusaya) bacteria, and parasitic bacteria such as Delobibrio. Research on item 1) is being pursued within the category of "Research Concerning Technology for the Utilization of Deep-Water Marine Resources," usingscience and technology promotional funds from the Science and Technology Agency. Research on item 2) is underway as a part of the Ministry of Agriculture, Forestry and Fishery research on aquaculture, while item 3) is covered under such areas of research as the Marine Ranching Project (MRP, integrated research on the development of fish farming as a development of coastal fishing resources), a large-scale independent research project of the Ministry of Agriculture, Forestry and Fishery resource department, and the previously mentioned "Operational Countermeasures for Prevention of Epidemics in Fish"

through the research department of the Fisheries Agency. Research on item 4) is proceeding under the Biomass Project (integrated research on the development of efficient technology for the utilization of biological resources) a large-scale independent research project of the Ministry of Agriculture, Forestry and Fishery resource department. Research on item 5) is included under the Red Tide Countermeasures Project at the Fisheries Agency, where research on natural enemies of the Red Tide organisms is progressing. Specific bacteria are recorded and preserved through the Gene Bank of the Ministry of Agriculture, Forestry and Fishery.

3. Marine Plants (Seaweeds)

For convenience, marine plants can be divided into two groups: microbial seaweeds and large seaweeds.

(1) Microbial Seaweeds

In the culturing of fish and shellfish, diatoms and green marine plants, such as marine chlorella, are widely used to feed fingerlings and small animals raised as fish food. Intensive research is thus progressing with regard to the physiology, ecology, and genetics of these plants. Detailed research is also underway concerning the Flagellatae organisms which cause the Red Tide, with most of the work being carried out under the Project to Develop Technology for the Prediction of Red Tide Occurrence, funded by such sources as pollution prevention test research grants from the Environment Agency, and the Red Tide Countermeasures Project sponsored by the Fisheries Agency. In recent years, in particular, there has been considerable progress in research on substances causing allelopathy or which will inhibit growth and reproduction among the Red Tide organisms, with increasing emphasis being placed on understanding these substances at the molecular and genetic levels.

(2) Large Seaweeds

The cultivation of laver is particularly advanced. Focusing on this area, since 1986 the Ministry of Agriculture, Forestry and Fishery has been working on a large-scale independent research project called Integrated Research on Biotechnology and Plant Cultivation, which has led to improvements in laver cell protoplast formation and cell fusion technology. This project and the Ministry of Agriculture, Forestry and Fishery Biomass Project have also studied kelp production, providing a broad base of biotechnology information with regard to large brown seaweeds.

Large brown seaweeds have been used for many years as a source of sodium alginate and other industrial materials. Recently, more and broader applications of seaweed constituent materials have been developed, so that seaweeds have become a source of mannan, iodine, and cellulose, as well as alginic acid. They are now widely used as safe fillers, stiffeners, and materials for glues. Large brown seaweeds are also an important source of vegetable food for such animals as abalone and sea urchins, and cannot be ignored when studying the cultivation of theseanimals. Therefore, technology for the propagation of large brown seaweed has been developed under the Ministry of Agriculture, Forestry and Fishery large-scale independent Marine Ranching Project, and "Seaweed Forests" are becoming quite common along the coast in various areas around Japan. Just as those for plants raised on the land, the basic technologies requirements for their biotechnology (such as callus formation) have nearly been perfected.

4. Marine Invertebrates

This category includes a large number of animal types, from the single- celled animals through the Protochordata, many of which live only in the sea. Animals currently used in marine production include: 1) the Rotifer Annelida, necessary in raising young fish; 2) the Porifera (sponge); 3) the Anthozoa (coral); 4) the sea urchins; 5) the nereids; 6) shrimps and crabs; 7) squid, octopi, and shellfish; and 8) the ascidians.

With regard to item 1), the "Shiotsubo" rotifer comprise the basic feed in the technology developed independently by Japan involving the cultivation of marine fish. Research in this area is, therefore, essential. Methods have been developed for the mass cultivation of micro-cellular rotifer, which originally were grown naturally. At the same time, ecological differences have been emphasized and divided into systems, with study focusing not only on physiology and ecology, but also on nutritional value and genetic differences from neighboring types. This area of research is currently considered to contain important questions with regard to marine aquaculture R&D, and is being pursued by a number of researchers.

Item 2) has been a focus of applied research for some time, but little progress has been made on propagation technology. A specific Porifera bioactive substance was discovered recently, and rapid developments in the area of sponge biology are underway.

The Anthozoa, item 3), can be divided into jewelry applications and coral reef construction. Due to the decreasing supplies of jewelry coral, the development of technology for coral propagation is eagerly awaited. There is considerable interest in clarifying the reef-building mechanism, both because of the relationship between the global increase in carbon dioxide gas and the activity of reef-building coral, particularly the carbonate-fixing capabilities of this coral, and also due to the desire to maintain territory and protect tourism resources. Coral reefs form unique ecological systems in the middle latitudes of the Pacific Ocean, so research on reef-building coral is necessary in order to develop reef areas.

The propagation and cultivation of sea urchins, item 4), was begun several years ago, and advances in research involving cultivation methods are anticipated. This research is being carried out at the various prefectural cultivation centers, and also under the aegis of the Ministry of Agriculture, Forestry and Fishery large-scale independent Marine Ranching Project. In addition, the new Biocosmos Project (integrated research on clarifying ecological mechanisms for operations in agriculture, forestries, and fisheries, and

development of appropriate control technology) of the Ministry of Agriculture, Forestry and Fishery scheduled to begin in 1989, will clarify interactions between seaweeds at the physical level.

The cultivation of nereids, item 5), is becoming popular, with DNA operations such as triploidism being conducted. A number of physiologically active substances of the nereids have become targets of study. For example, nereids contain substances which are attractive to fish, as well as substances which are poisonous to higher animals. Inaddition, the secreted adhesive for tube formation present possibilities for the development of new adhesives for use in underwater construction.

Shrimp and crabs, item 6), are important marine organisms in their own right. In addition, a specific constituent of their shells is being used as a material for artificial skin, an area which has become a major target for marine biotechnology. Research on the internal information systems of this type of shellfish is proceeding under the Biomedia Project (integrated research for the development of new agricultural, forestry, and fishery technology for the clarification and control of bio-information), a large-scale independent project of the Ministry of Agriculture, Forestry and Fishery.

With regard to item 7), the squid nervous system is providing research materials for fifth-generation computer development, and squid ink is being used as a raw material in liquid crystals, so there is considerable proliferation of non-food applications for animals which were originally thought of merely as a food. The anti-tumor component of squid and octopus ink is attracting attention, as are other raw materials for use in medicines. The biotechnology of shellfish is being researched under the auspices of the Project To Develop Cultivation Technology for the Generation of Sexuality (Female), etc., in Fish and Shellfish, a special research project of the Ministry of Agriculture, Forestry and Fishery. In addition, another Ministry of Agriculture, Forestry and Fishery special research project entitled "Development of Cultivation Technology for Shellfish Such as Abalone and Clams" is scheduled to begin in 1989.

Research on shellfish chromosomal operations, etc., is also being carried out primarily by prefectural research organs throughout Japan under the Project for the Promotion of Regional Cooperation of R&D for New Technology Such as Biotechnology, a project of the research department of the Fisheries Agency.

The ascidians, item 8), are cultivated solely by Japan, with related research being quite advanced. A number of marine organisms are known to have the capability for bio-concentration of micro-quantities of certain substances (the ascidians can concentrate vanadium), but a number of points remain unclear about the precise mechanism involved. These points have become research topics.

Marine invertebrates comprise many types, are widely diverse, and have a completely different evolutionary history than that followed by land organisms. Therefore, they offer a treasure house of new biofunctions and specialized genetic resources.

5. Marine Vertebrates

There are tens of thousands of types of fish in the world. Of these, several hundred are targeted by fishermen, and approximately 100 hold an important industrial position as candidates for aquaculture. Research concerning biotechnology and fish is proceeding actively under the aegis of the Project To Develop Cultivation Technology for the Generation of Sexuality (Female), etc., in Fish and Shellfish and also the Project for Domestication by Nuclear Transplantation and Successful Individual Creation of Fish, special research projects of the Ministry of Agriculture, Forestry and Fishery, as well as the Project for Projection of Regional Biotechnology R&D, sponsored by the research department of the Fisheries Agency. Tests involving generating sexuality (male and female), polyploids, cell fusion, etc., have been made on 30 types of fish. The number of eggs available from individual accounts for the rapid biotechnological advances with the types of fish used, making mass processing feasible. In addition, artificial fertilization and hatchingtechnologies are nearly perfected. Polyploidization technologies, such as temperature shock and high-pressure processing, which are well suited to mass processing, have also been developed. This has made possible rapid biotechnological advances, particularly in the area of chromosomal manipulation in fish.

Fish biotechnology, of course, also includes recombinant DNA techniques and other genetic manipulation. However, there is currently insufficient practical genetic analysis, so future developments have been forced to wait on further basic research. Under the Biomedia Project, a large- scale independent research project begun by the Ministry of Agriculture, Forestry and Fishery in 1988, the focus will be primarily on the clarification of the mechanism of in vivo information transmission at the cellular level with regard to maturation and egg production in fish. This research is expected to provide basic information to clarify useful genetic characteristics. In addition, the same organization is scheduled to begin "integrated research for the clarification of ecological mechanisms concerning agriculture, forestry, and fisheries, and development of optimal control technology." This research has as its objective explaining on a physical level, such phenomena as the return and recognition mechanism in migrating fish, the formation of schools, and the mechanisms involved in maturation, egg production, and migration. The results of this research are expected to provide the foundation for fish-related biotechnological developments.

Research Projects Related to the Development of Unused Marine Bioresources

1. Project for High-Level Multipurpose Technology Development Concerning Unused Marine Resources (Research Section, Research Department, Fisheries Agency)

This project is scheduled to begin in 1989, with a first-year projected budget of ¥110 million, and to

continue for 5 years. The program is outlined below, with a summary of objectives.

(1) Objectives

In order to reevaluate marine bioresources in the waters around Japan, and to use these resources effectively, steps are being taken to develop efficient uses for such materials as the currently unused internal organs and bones of harvested fish. These unused marine resources clearly contain a variety of useful properties in such areas as physiological constituents, productive capabilities, and environmental functions which are unique to marine organisms. For example, the antiseptic action of nericetoxin, found in *Lumbriconereis heteropoda*, the hypotensive action of laminarin, found in kelp, and the antiseptic and antifungal actions of saponin, found in *Holothuroidea* and *Asteroidea*, have all been confirmed. However, the concentration of these useful properties in the marine organisms is quite low, and considerable risk and cost would be involved in developing the practical technology for their utilization. Therefore, although these products would be useful in a wide range of areas, including the production of food, medical products, and industrial goods, their application has been delayed. This project is designed to bring together research results from university and marine research laboratories, to expedite the development of technology by private industry, to develop technology for the utilization of unused marine bioresources, thereby increasing the value of Japan's marine resources, and to develop new areas of demand.

(2) Contents of the Project

1) To provide methods for separating useful properties from within currently unused marine resources, including those of high-performance physiological activation, taste and smell, pigments, and other advantageous properties.

2) To develop efficient separation and extraction technologies using such methods as membrane separation, liquid chromatography, and supercritical gas extraction.

3) To develop and evaluate technology for applying these useful properties to foods, propagation and cultivation, etc.

Figure 1 illustrates this project in outline form.

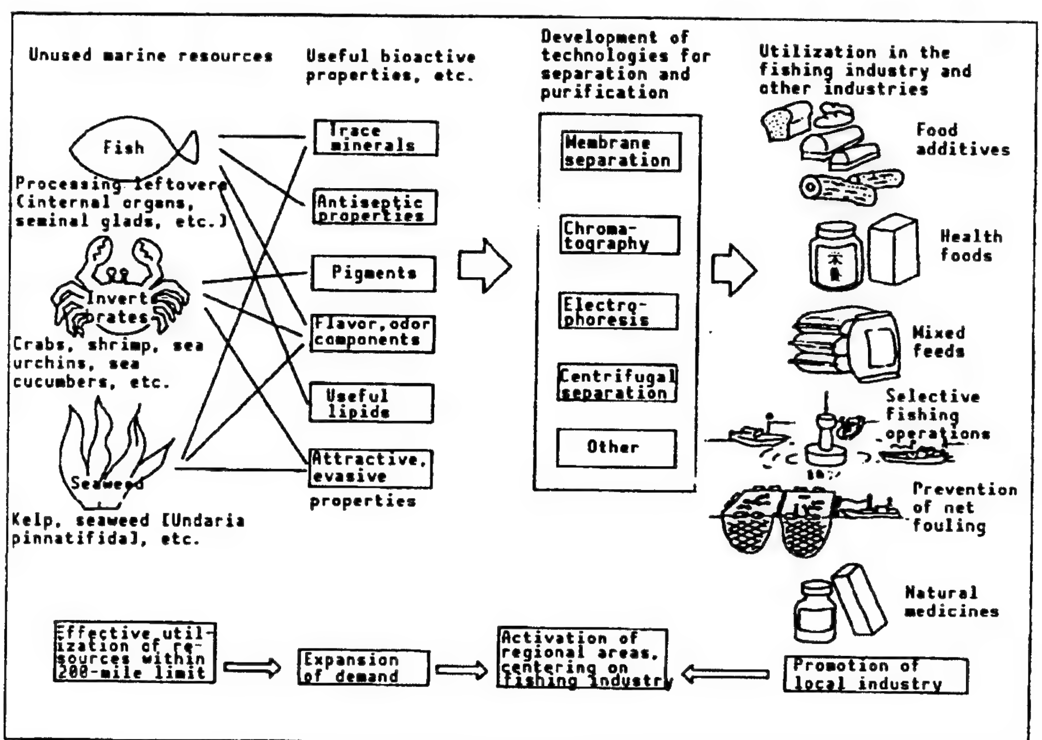


Figure 1. Project Outline for the Development of Technology for Improved and Diversified Application of Unused Marine Resources

Key: Scheduled to begin in 1989, this project is designed to encourage the development of technology by private industry, to develop technology for the use of unused marine resources, to increase the value added to marine resources, and to develop new areas of demand. The projected budget is ¥110 million for the first year, with plans to continue the project for 5 years.

2. Integrated Research for the Development of Technology To Clarify and Evaluate the Mechanism of Production of Useful Characteristics by Marine Organisms (Integrated Research Problem Funded by a Science and Technology Promotional Grant From the Science and Technology Agency and Sponsored by the Ministry of Agriculture, Forestry and Fishery Technology Council Office)

This research is not limited to the area of marine products, but instead includes fundamental elements of marine biotechnology research. Applied and practical research can only grow if it is rooted in this basic knowledge.

(1) Objectives

As we look toward the 21st century, the development of improved marine product technology is a particularly suitable topic for study in Japan, since it is both a marine nation and scientifically advanced. This research is designed to develop the basic and fundamental technology which will be required for the promotion of bioindustries in the next century. The work will involve three-dimensional ocean spaces, and will focus primarily on searching for bio-resources, the chemical classification of marine organisms, and discovering the mechanisms by which properties are produced. The new technology required for evaluating the usefulness and improving the utilization of marine biofunctions and marine organisms will require a joint effort among government, industry, and academia. This research will provide a firm foundation for improving the utilization of marine organisms by Japan.

This work can be expected to be the source of major advances in bio- industries in the 21st century, and also to be of international importance insofar as it results in improved global utilization of marine bio-resources, which will benefit world harmony.

(2) Research Outline

1) To develop basic technology for the chemical categorization of marine organisms (establishment of new chemotaxonomies and genotaxonomies).

2) To explain metabolism and physical production functions of marine organisms under special environments (expression of functions under special physical, chemical, and biological environments).

3) To develop technology for evaluating the usefulness and modifying natural marine organisms (establishing of extraction and evaluation technology, and chemical modification technology).

4) To develop technology for converting marine organisms to resources, and for their more efficient use (establishing technology for the stabilization and preservation of useful properties and mass cultivation and propagation, as well as efficient production technologies).

This research is outlined in Figure 2.

3. Research on the Effective Utilization of Deep-Water Resources (Integrated Research Funded by a Science Technology Promotional Grant From the Science and Technology Agency) (1986-1990)

This topic covers research concerning the physiological and ecological characteristics of deep-water microorganisms, their investigation and cultivation, and their effective utilization. The specialized organisms which live under ultra-high pressure are expected to exhibit special biological functions and unique genetic structures. Further clarification of these points should be useful in the cultivation of these organisms on land in special tanks.

New Research Structure

For research in new fields, such as biotechnology, and for the development of new areas of technology based on new concepts, new forms of research organizations are required. This is truly a case of "new wine into new wineskins." However, it is impossible for the limited personnel currently involved to respond to all of the demands for research coming from the multitude of diversified industrial fields. In response to new developments in science and technology, such as those in marine biotechnology, the Fisheries Agency has reorganized its Tokaiku Marine Laboratory as the Central Marine Laboratory. In addition to responding to new demands from society, the agency is also engaged in promoting the construction of its largest research ship, the Kaiyo Maru. Plans for the new Central Marine Laboratory focus primarily on the two areas of research illustrated in Figures 3(a) (biochemistry) and 3(b) (biofunctions). This laboratory is expected to work together with regional marine laboratories and cultivation laboratories in an aggressive approach to the various aspects of marine biotechnology. The new research ship, at a total construction cost of approximately ¥6 billion, is scheduled to be equipped with facilities for the genetic analysis of useful marine organisms and for deep-water organism-sampling, and is expected to provide extremely useful information.

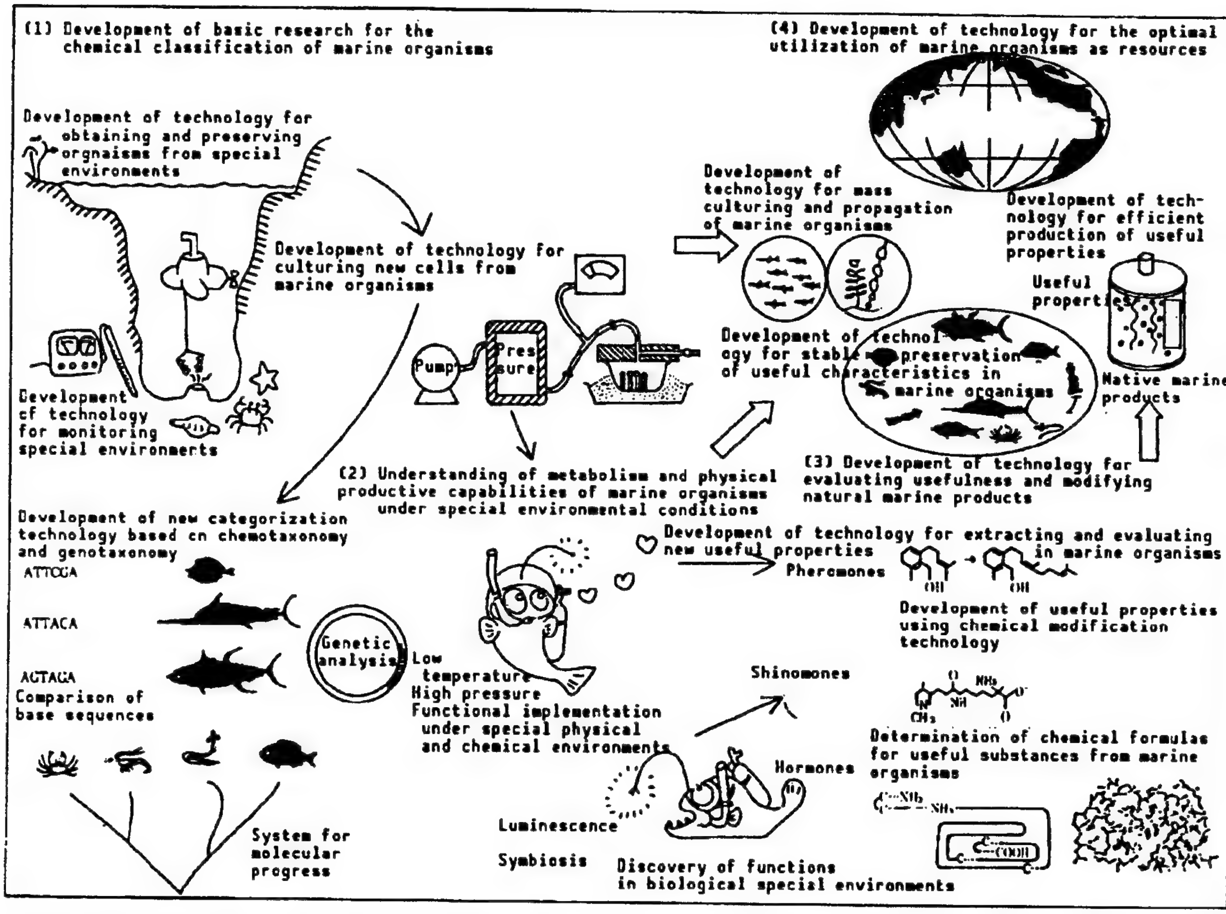
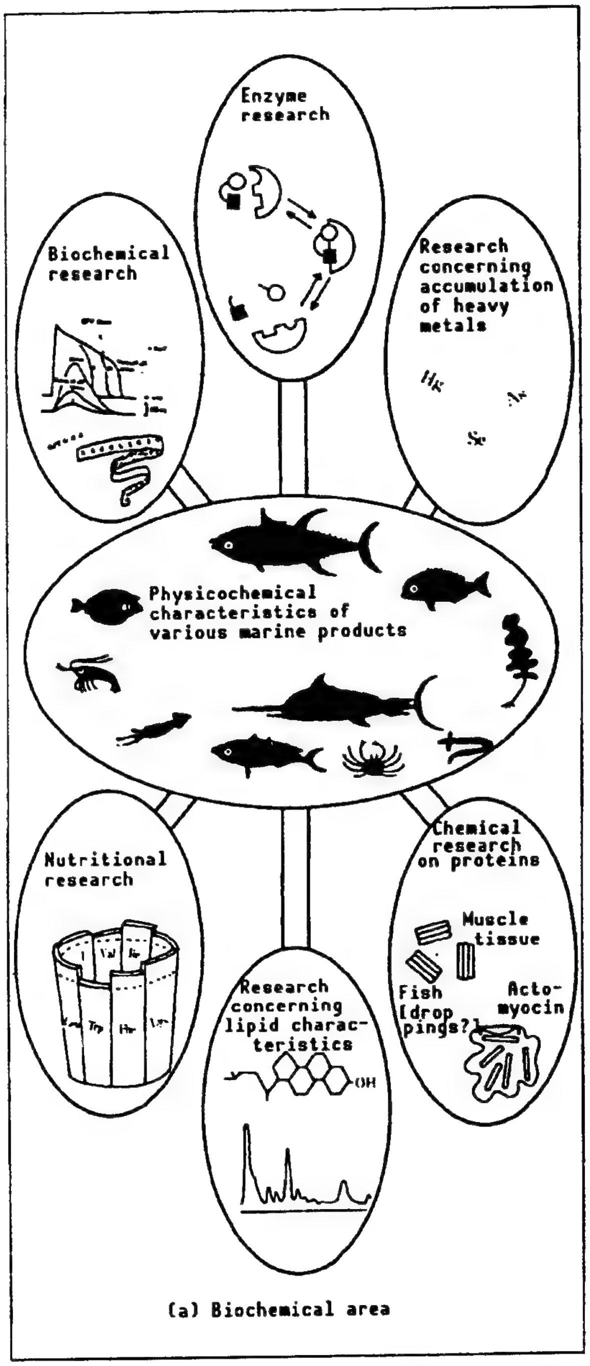


Figure 2. Integrated Research To Clarify Mechanisms for Production of Useful Characteristics in Marine Animals, and Development of Technology for Evaluation

Key: This project involves the integration of multidisciplinary work among government, industry, and academia. It is focused primarily on the search for marine resources in a three-dimensional space within the ocean, and the chemical categorization and characteristics of the marine organisms discovered, with emphasis on R&D concerning new technology for the optimization and practical application of these resources.



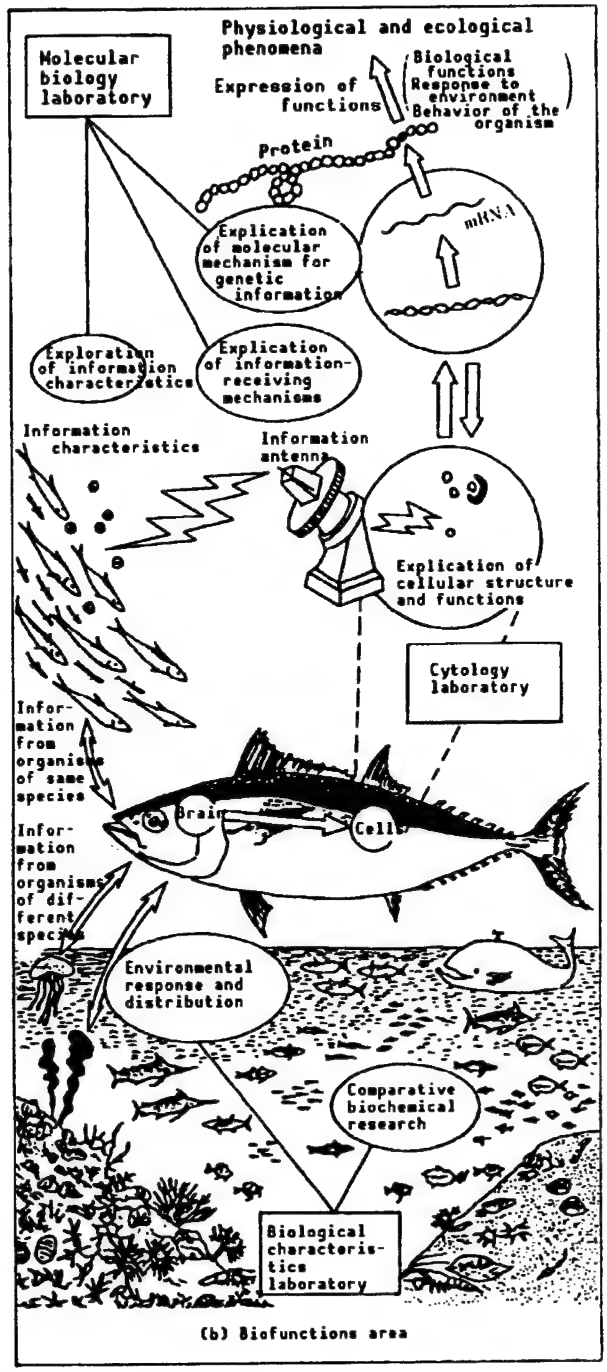
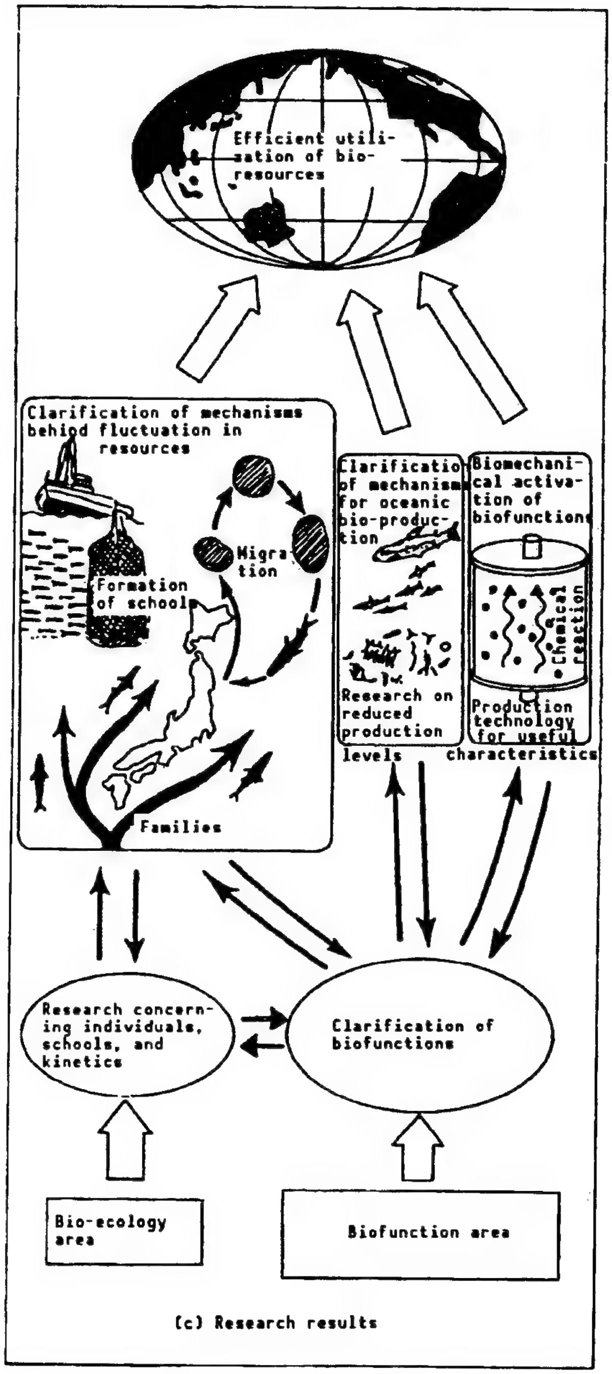


Figure 3. Outline of Activities in Research Fields Related to Marine Biotechnology, as Conducted in New Marine Laboratory

Key: The Central Marine Laboratory, a reorganization of the Tokaiku Marine Laboratory, is actively involved in marine biotechnology, sharing cultivation research with the various regional marine laboratories. The primary focus is on the two fields shown above, (a) biochemistry and (b) biofunctions. By next summer, the results shown in (c) are expected.



[Continuation of Figure 3]

Deep-Water Resources Studied

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[Article by Nobuaki Arai, Science and Technology Agency: "Toward the Practical Understanding and Utilization of Deep-Water Resources"]

[Text] With such developments as the implementation of the diving research ship "Shinkai 2000," progress is being made in deep-water explorations and a wide variety of new information is coming to light. There is considerable interest in the utilization of heretofore unknown applications of such deep-water resources as nutritive salts and deep- sea organisms. New research emphasizes the practical investigation of the efficient utilization of these resources, as well as the development of technology to permit their development and application.

As part of its program for the promotion of marine development, the Science and Technology Agency is developing fundamental devices and systems to promote marine science and technology, including a diving research ship system and an undersea operations system to be implemented by the marine science and technology centers administered by the agency while, at the same time, providing overall coordination of leading-edge and basic R&D in keeping with the objectives of the Science and Technology Council.

As a part of the subjects being studied, this paper will introduce some aspects of R&D which apply to developments in marine biology.

Areas Being Handled by the Marine Science and Technology Center

The Marine Science and Technology Center (Yokosuka City, Kanegawa Prefecture) was established in 1973 with the objective of promoting Japanese marine science and technology, as prescribed in the Marine Science and Technology Center Act, in accordance with the call for cooperation between industry, academia, and government. Since its opening, the center has conducted research in a number of areas, including the Seatopia Plan experiments in underwater living, the "Kaimei" experiments involving the wave-powered generation of electricity, and the development of a deep-water research ship system. The areas of research which have the most bearing on marine biology will be summarized here.

1. Diving Research Ship System

The Marine Science and Technology Center began developing a 2,000-meter diving research ship system in 1977. In 1981, the Shinkai 2000 and its mother ship the

Natsushima (1553 t) were completed. For rescues and preliminary tests with the Shinkai 2000, the Dolphin 3K was completed in 1987. This unit can conduct unmanned tests to a depth of 3,300 meters.

This diving research ship system operates through the cooperation of related agencies, universities, and other organizations in the areas described below.

(1) Investigation of Deep-Water Resources

Searches for deep-water petroleum and natural gas reserves in the continental shelf, investigate mining resources, such as manganese nodules, on the ocean floor.

(2) Investigation of Deep-Water Bioresources

Studies unused deep-water resources, such as bottom cod, and groupings of organisms dependent on chemical synthesis and production in regions of underwater hotsprings or upwelling of cold water from dislocations or faults.

(3) Investigation of Status of Underwater Structures

Studies the condition of transoceanic cables, etc.

(4) Investigation of Marine Physics

Studies such factors as marine water temperature, salt content, and current direction and speed, which are closely related to marine shipping, climate, and production.

(5) Investigation of Geophysics

Studies undersea formations and structures, forces, and magnetic fields, which are related to earthquake prediction, etc.

By the end of 1988, the research diving ship had completed approximately 380 missions, focusing on the above areas. The ship compiled information on the environment of shrimps and crabs and on benthos groups, and discovered a number of unique lifeforms, such as the tubeworms and white shellfish grouped in the vicinity of underwater hot springs (Photograph 1 [not reproduced]).

A diving research ship system of the 6,000-meter class is currently being developed. This unit, the Shinkai 6500, and its mother ship, the Yokosuka (approximately 4500 t), are scheduled to begin operation in 1990. As its name suggests, the Shinkai 6500 is capable of diving to depths of 6,500 meters. This will permit exploration of 98 percent of the world's ocean floor, and 96 percent of the ocean floor within Japan's 200-mile limits. This will be the world's deepest-diving ship. It is expected to provide highly valuable information.

2. Underwater Operating Systems

Simultaneously with the development of the diving research ship system, the agency has also been pursuing the establishment of saturation diving technology at depths of 300 meters, required for the development of the rich bioresources and petroleum reserves which are expected to be discovered on the continental shelf, plus the R&D of systems for underwater operations.

Saturation diving refers to a diving method whereby the gas in the environment and the gas contained within the human body are at the same pressure. This diving technology makes it possible for men to work safely underwater for extended periods of time (a month or longer) as long as compression and decompression are conducted under specific conditions.

At the Marine Science and Technology Center, a laboratory has been equipped with a diving simulator (a device which duplicates a high- pressure undersea environment up to a water depth of 500 meters) in order to develop and check saturation diving technology. This system has been used repeatedly to conduct both physiological and psychological simulation tests, as well as to collect basic data. In addition, a special underwater operations test ship, the Kaiyo (2489 t), has been developed for actual on-site testing. This ship was completed in 1985 (Figure 1).

Kaiyo is a research ship designed to conduct a variety of marine research projects, including experiments in diving operations, research in undersea mapping, and unmanned exploration of the ocean floor. It has the following characteristics. 1) The ship is of the half-submerged twin-hull type, providing exceptional stability on the ocean and increasing the area available for operations. 2) To improve the capabilities of the sonar equipment, sources of vibration and noise, such as major machinery, have been placed on deck above the water level, with an electric propulsion system used to drive the ship. 3) The ship has been equipped with automatic position-maintaining equipment to improve stability during diving experiments and underwater operations. 4) The ship uses multi-narrow-beam sonar, which makes it possible to investigate the ocean floor to a depth of 11,000 meters. 5) The ship is constructed around a central well, so that the raising and lowering operations of such equipment as the submersible decompression chamber (SDC) can be conducted under conditions of minimum pitching or other movement.

Experiments are currently underway for the New Seatopia Project, designed to develop diving operations technology at depths of 300 meters. In July of last year, in marine experiments in the Hatsushima Sea in the vicinity of Shizuoka Prefecture, saturation diving and undersea operations experiments were conducted without incident at depths of 300 meters.

Kaiyo was equipped with a deep-sea television system for studying the area around an underwater volcano at a depth of 450-500 meters, off the coast of Ogasawara. Crabs with atrophied eyes were successfully collected, and these animals are now being kept alive and displayed at Tokyu Yuko Marine Park.

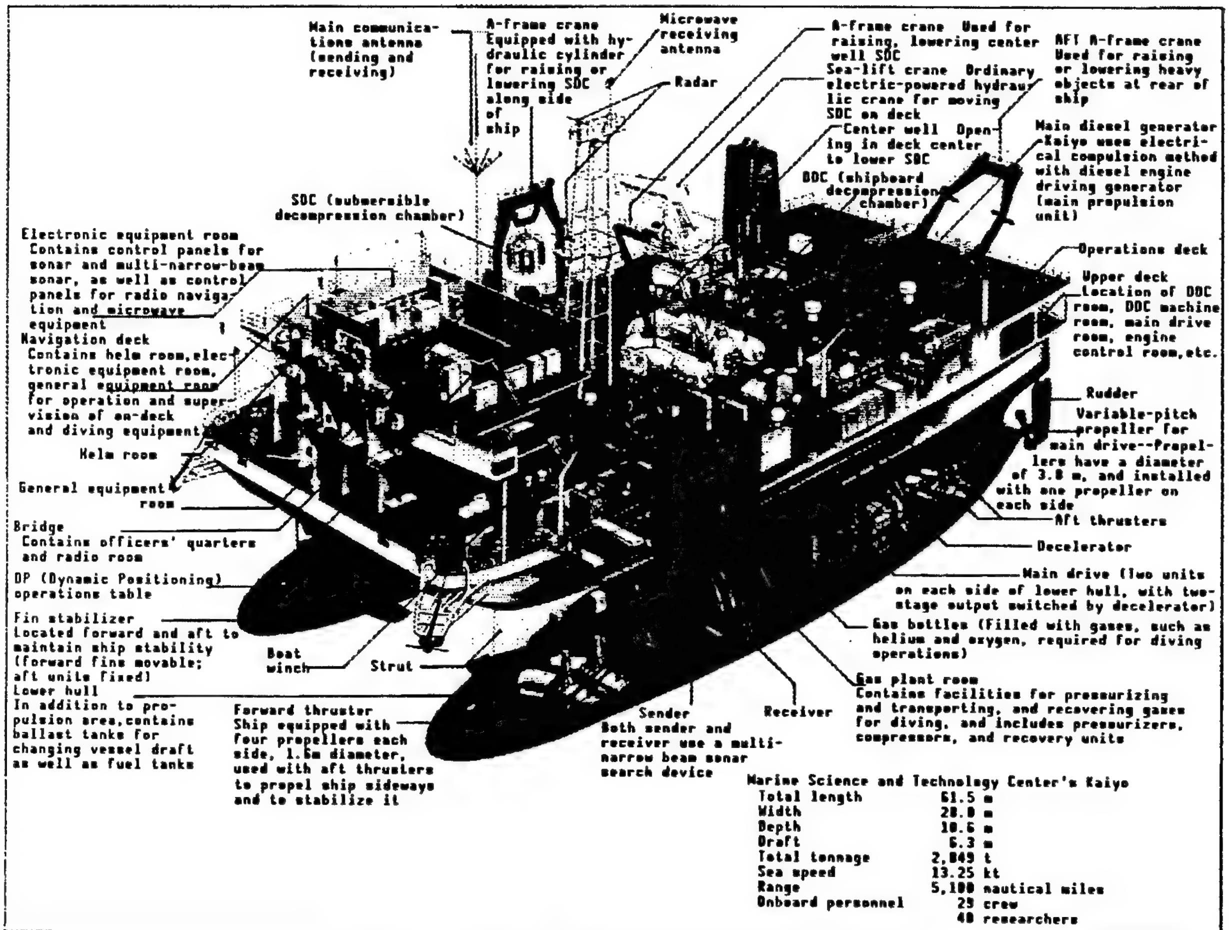


Figure 1. Underwater Operations Test Ship, the Kaiyo

Key: This research ship carries out a variety of marine research projects, including diving experiments, undersea mapping, and deep-water exploration with unmanned probes.

As noted above, man's groping attempts at deep-water research in the past are being replaced by technology which permits direct human entry, observation, and exploration of the deep-water environment.

Projects and Research With Science and Technology Promotional Funds

Projects and research funded by science and technology promotional funds must follow the guidelines established by the Science and Technology Council (chairman: Prime Minister Takeshita), which is an advisory organ to the Prime Minister's Office. These funds are intended for work involving basic and leading-edge research problems, and are awarded to integrate and promote efficient communications between industry, academia, and government. Since the Science and Technology Promotional Fund was first established in 1981, a large number of research projects have been implemented, with excellent results. There has been a real increase in the fund's budget, which broke the ¥10 billion mark in1989, reaching ¥10.1 billion.

Marine science and technology is one of the major research fields for the Science and Technology Promotional Fund. Projects currently underway which are related to the field of marine biology include "Research Concerning the Development of Technology for the Effective Utilization of Deep-Water Resources (Phase I 1986-1988, Phase II 1989-1990)," and Research Concerning an Explanation of Ocean Plate Formation (Rift Type) in the South Pacific (Phase I 1987-1989, Phase II 1990-1991). These projects are outlined below:

1. Research Concerning the Development of Technology for the Effective Utilization of Deep-Water Resources

In the past, considerable progress was made in using marine resources, especially fish to provide food. In recent years, great advances have been made in the efficient utilization of the marine environment and of

newly-discovered useful characteristics. The ocean now offers a veritable treasure house of genetic resources, representing important biotechnological elements.

Deep-water resources of particular interest include such items as a rich variety of nutritional salts, pure seawater, energy generation based on the temperature differential between deep-water and surface layers, space both under water and on the ocean floor, and special properties which are anticipated to be obtained from deep-water organisms.

However, these deep-water resources are not yet within our grasp. In fact, not only is there still insufficient technology available for their development and utilization, but research on their efficient use is only just beginning.

For this reason, in 1986 the Science and Technology Council decided to initiate and promote a 5-year plan under the direction of the chairman of the Research Promotion Committee, Professor M. Hirano of Tokai University. The program was titled "Research Concerning the Development of Technology for the Effective Utilization of Deep-Water Resources" (Figure 2).

This research involves the implementation of research regarding technology for the efficient transportation of seawater from the deep-water environment to the surface

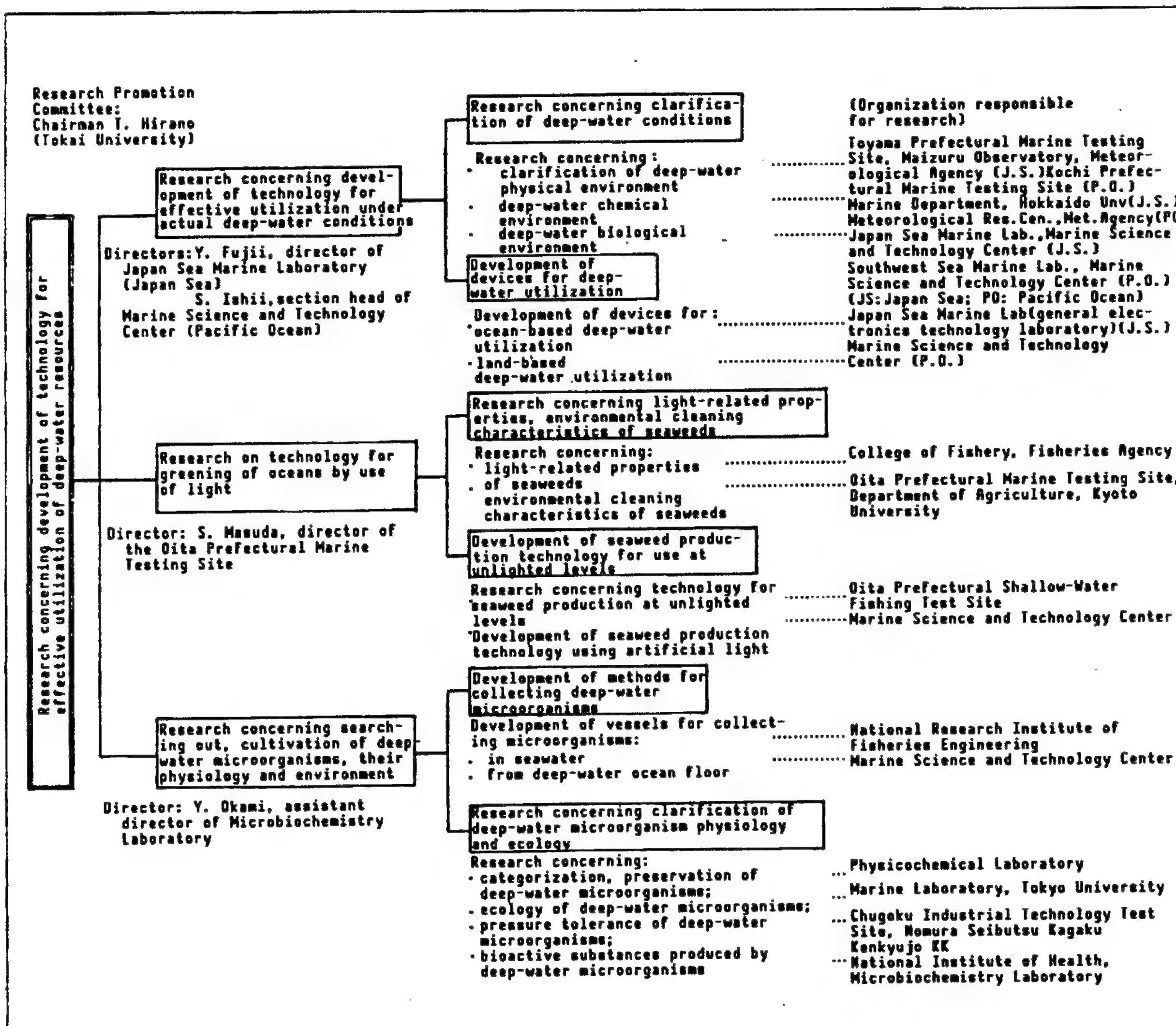


Figure 2. Outline of Research Concerning the Development of Technology for the Effective Utilization of Deep-Water Resources

Key: The illustration outlines the structure of research implemented during the first period (1986-1988).

of the ocean or to land, and for the maintenance of the organisms within this seawater, technology to assist in the lighting and construction of underwater operational sites and protect the marine environment, and technology for the discovery and cultivation of marine microorganisms living under special environments, such as high pressure, etc. These studies are proceeding under the respective titles of "Research Concerning Efficient Utilization Technology Based on Actual Deep-Water Conditions (Japan Sea and Pacific Ocean)," "Research on Technology for the Greening of the Oceans by Use of Light," and "research Concerning the Searching Out and Cultivation of Deep-Water Microorganisms, Their Physiology and Environment." Phase I will be concluded this year, with Phase II scheduled to begin next year.

Below is an outline of the research from Phase I, along with results andprojected developments.

(1) Research Concerning Efficient Utilization Technology Based on Deep-Water Sampling Conditions

1) Objectives of the research

This research details the physical, chemical, and biological characteristics of deep-water seas in the vicinity of the Japanese islands, for a variety of areas which differ regarding such points as current flow and geological formation, and investigates the potential effectiveness of deep-water organism production under these location conditions.

Two systems have been conceived for effective deep-water utilization: an ocean-based facility and a land-based facility (Figure 3). Under this research, Toyama Bay on the Japan Sea has been established as a model ocean area for the ocean-based facility. A self-sustaining deep-water- powered facility will be developed which utilizes energy from the temperature differential between deep-water layers and surface water. Water from the lower layers will be drawn up and sprayed onto the surface area, enriching the water with a variety of nutritional salts, and increasing the production of organisms.

An area near Murotomi City has been selected as a model for the land- based facility. A land-based facility equipped for deep-sea water utilization will be developed using an efficient method to raise the water from deep-sea levels to the land-based facility, and technology will be developed for efficient organism production based on the effective utilization of the pure seawater, temperature characteristics, and the rich load of nutritional salts in this deep-water layer.

2) Outline of results

(i) Japan Sea

Studies of deep-water conditions have been carried out in accordance with the Physical Environment Regulation Act, with deep-water investigations performed in the Japan Sea showing that sediments formed at approximately 39°-40° north latitude are transported to Honshu beaches. In accordance with the Chemical Environment Regulation Act, the development and application of new analytical techniques, such as the use of CFCs (clorofluorocarbons), have been used to confirm that deep-level seawater in the Japan Sea, conventionally thought to maintain the same location for an average period of 1,000 years, actually has a period of 30-50 years. Under the Biological Environment Regulations Act, research has shown that it is possible for a type of copepoda to be transported as far as the lower levels of Toyama Bay in their southward deep-water travels.

With the above results in mind, researchers commenced on the design and development of an ocean-based deep-water utilization facility containing the world's first generator powered by the seawater temperaturedifferential. In August of last year, a steel riser pipe reaching a depth of 300 meters was successfully installed. This will form a portion of the installation at Nagami City in Toyama Prefecture.

The main facility is scheduled to begin operations next year, implementing marine experiments which will involve the raising of 0.3 t of deep-level seawater per second, the spraying of this water on the surrounding sea area, and the regulating of the surrounding environment.

(ii) Pacific Ocean

The experimental sea area near Muroto City has shown that, regardless of the influence of the Japan Current, the deep-level seawater at the site where lifting is planned shows extreme year-round stability in terms of water temperature, salt content, and nutritional salts. In biological terms, the water is cleaner than is the surface layer water. In indoor experiments using on-site surface seawater for the cultivation of *Chaetoceros ceratosporum*, the surface water showed a longer period of transparency (lag time between introduction of the *Chaetoceros ceratosporum* and the beginning of propagation) than did the deep-level water from the Japan Sea, which was apparently related to the differences in organic matter contents and to the concentrations of inorganic forms of copper and iron found in the deep- level water.

The above results were taken into consideration during the design and development of the land-based facility for deep-water utilization. In December of last year, a rigid polyethylene riser pipe reinforced with steel wire and having an internal diameter of 125 mm and a length of approximately 2,650 m was installed using the reel barge method. (In- take pipes for both the deep-level and surface water were made of polyethylene because of the possible effect of metals on biological tests, and the pump was constructed of vinyl chloride as well). This made it possible to obtain water samples from a depth of 320 meters, as planned. In January of this year, the installation conditions will be checked by an underwater camera using the underwater operations research ship Kaiyo.

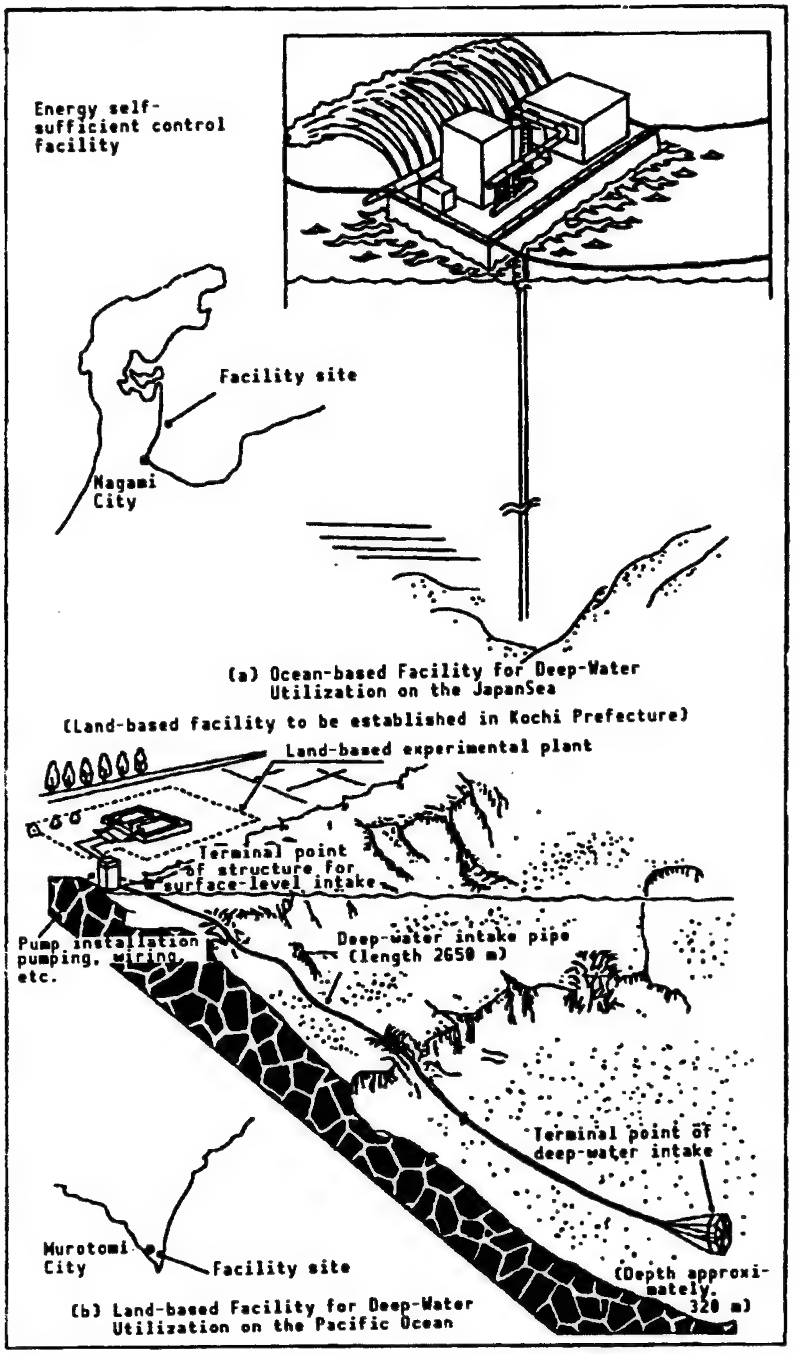


Figure 3. Development of Deep-Water Utilization Facility

Key: Development is underway for two different types of deep- water utilization facilities. A model energy-self-sufficient ocean-based facility (a) is scheduled for construction in Toyama Bay on the Japan Sea. A model land-based facility (b) is planned near Muroto City on the Pacific Ocean.

This facility is scheduled to become operational this year, lifting 460 t each of deep-layer water and surface seawater per day and conducting biological production tests, etc.

The land-based facility for deep-water utilization has been established in Kochi Prefecture.

(2) Research on Technology for Ocean Greening by Use of Light

1) Research objectives

Seaweed beds are said to have far-ranging positive effects on environmental cleaning and biological production. However, the physical, chemical, and biological mechanisms involved are not yet clearly understood.

This research is designed to study optical characteristics and how they affect the growth of seaweeds which make up the seaweed beds. It will also measure the environmental cleaning characteristics of seaweeds, including the effect of chemical factors, such a phosphorus and nitrogen, on environmental cleaning. In addition, based on these results, the project will develop an artificially illuminated seaweed production facility for use in the production of artificially lighted seaweed beds at levels which are too deep for seaweed growth by natural sunlight (insufficient sunlight for nutrient decomposition byphotosynthesis and absorption (Figure 4).

2) Outline of results

Saeki Bay in Oita Prefecture was selected as a model marine site, and basic data was collected for "kurome" (a type of kelp), "arame" (a type of brown algae), and "hondawara" (a type of brown algae) which make up the seaweed beds in this area. Data included the relationship between the light spectrum and growth, production volume per unit area of the marine site, the relationship between the amount of light accumulated and growth, and fluctuations in the physical environment of the seaweed beds (including such physical phenomena as the sinking of cold water from the beaches in winter, giving rise to the cascading phenomenon which affects growth in the beds, and the abrupt increases in water temperature in the summer when warm water from the ocean flows into the beds at ebb tide.

Based on the light-related characteristics of the seaweeds and the other characteristics determined from the above research, scientists designed, produced, and installed a device to introduce artificial light at the unlighted levels from the most efficient compensation point. This device consists of a 26-meter long superbuoy equipped with two experimental shelves, each 7 m in diameter, with metal halide lamps as the light source. It is constructed so that the light, powered by a land-based power source, is reflected from the experimental shelves. A land-based power source was used instead of sunlight in order to avoid difficulties in establishing accurate experiments. Great fluctuations in sunlight intensity occurs due to weather, and the complexity of the photoaccumulator

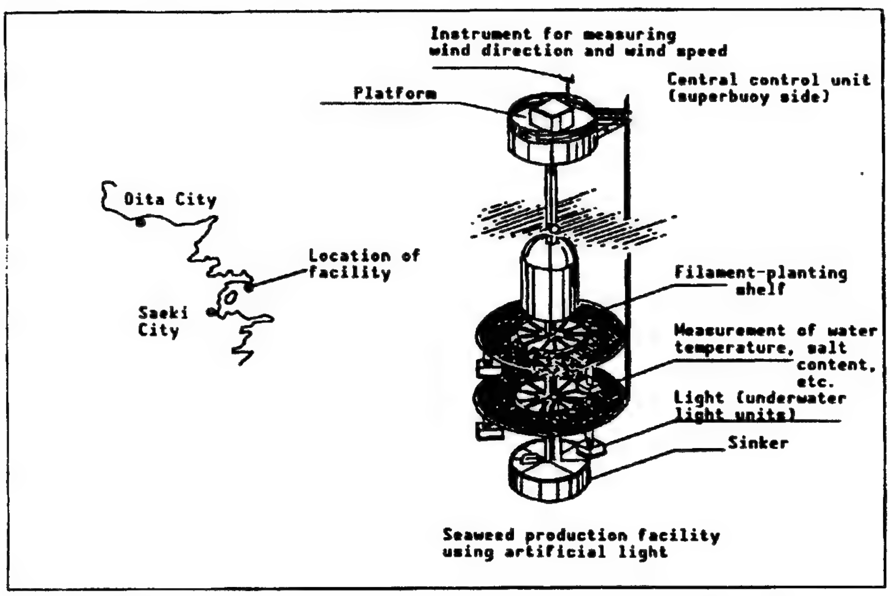


Figure 1. Development of Undersea Greening Project

Key: This seaweed production facility using artificial light was designed and developed for the formation of artificially lighted seaweed beds at depths where seaweed cannot grow because of insufficient sunlight. The facility has been established in Seaeki Bay, Oita Prefecture.

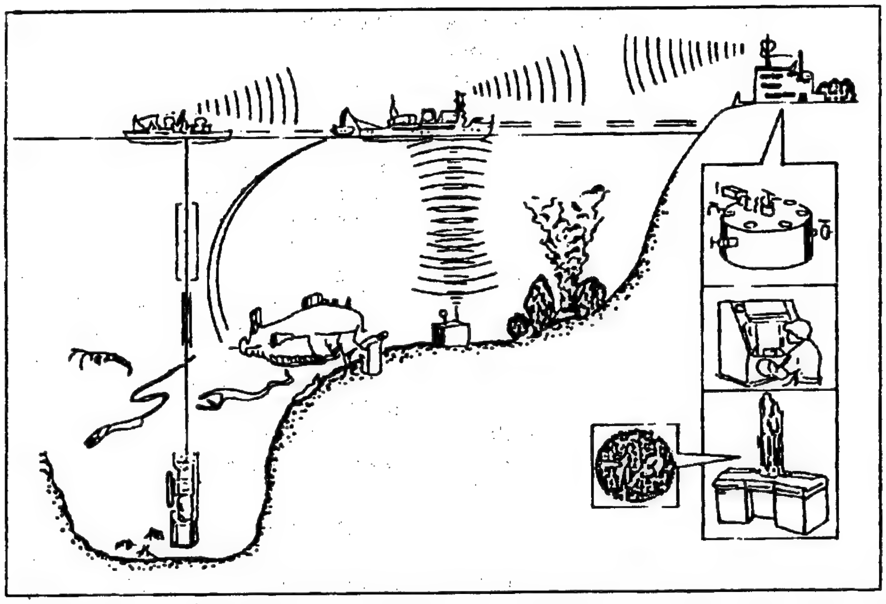


Figure 5. Development of Devices for the Collecting and Cultivation of Deep-Water Microorganisms

Key: A unified system is being developed whereby original pressure is maintained while samples are collected and separated and the microorganisms are isolated and cultivated. Research will be conducted on the categorization, preservation, and ecology of deep-water microorganisms, and concerning bioactive substances produced by these deep-water microorganisms.

mechanism was considered to be particularly inappropriate for use on a floating buoy.

Beginning next year, there are plans to install filament-planting mats containing shoots of such varieties as "kurome," "yatsumatamoku," and "akamoku," and to raise these plants experimentally under artificial light while, at the same time, investigating the effects on the surrounding environment as well as on fish and shellfish.

(3) Research Concerning the Searching Out and Cultivation of Deep-Water Microorganisms, Their Physiology and Environment

1) Research objectives

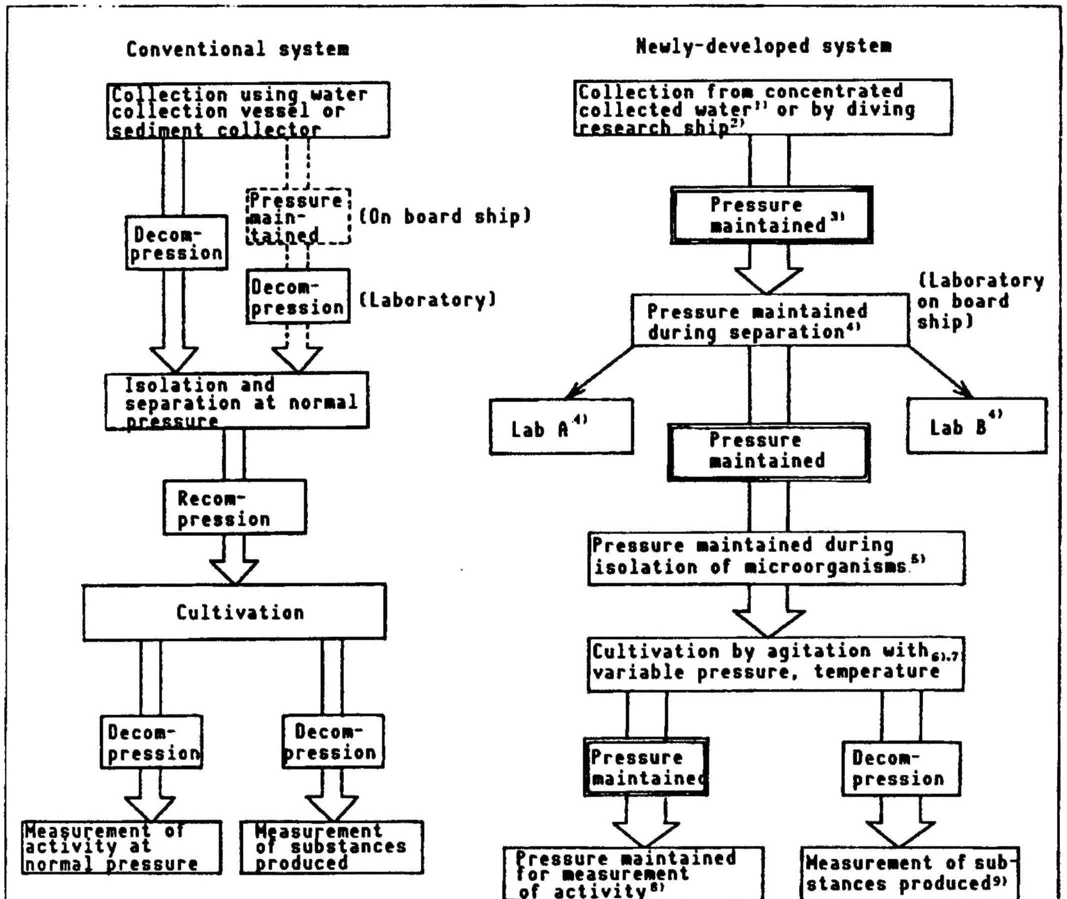
It is assumed that deep-water microorganisms will have physiologies and ecological functions differing from those of general microorganisms. They have thus generated considerable interest as useful microorganism resources. However, under conventional research, it has been extremely difficult to maintain the high pressure of the original collection site while collecting and separating samples and isolating and cultivating the microorganisms. Instead, operations have tended to involve repeated compression and decompression.

Under the present research project, a system has been developed whereby the ample collection and separation and the isolation and cultivation ofmicroorganisms are all conducted while maintaining original site pressure. This makes it possible to research to categorization, preservation, and ecology of deep-water microorganisms, and to conduct research on the pressure tolerance of cell membranes and enzymes, as well as to study the bioactive substances produced by deep-water microorganisms (Figure 5).

2) Outline of results

The year before the actual research was begun, this research problem was the topic of a feasibility study investigating the outline of the design for maintaining original pressure while collecting and separating samples and isolating and cultivating microorganisms. Methods for encouraging further research, etc., were also investigated.

As a result of this inquiry, a collection device was developed which would allow the operation of a manipulator for collecting deep-water samples from on board the ship and collecting deep ocean floor samples using the diving research ship Shinkai 2000 (with the understanding that this task would be taken over by the Shinkai 6500 in the future). Samples were successfully collected from depths of approximately 6,000 meters and 2,000 meters, respectively, and separated, while maintaining the pressure of the original collection site. The system was completed by the development of a device for isolating the microorganisms under a dry helium pressure environment, as well as the development of a device for measuring the amount of heat generated while cultivating these microorganisms under static water pressure, thereby achieving the original goal of maintaining uniform pressure from the time of collection (Figure 6).



Characteristics of the new system:
1) Samples can be concentrated approximately 100 times for collection
2) Original site can be directly observed while collecting deep-water samples
3) Samples can be brought on board while being maintained at original collection pressure
4) Deep-water samples can be divided among several different research groups while being maintained at the original pressure
5) Microorganisms can be isolated and purified from sample in a high-pressure environment
6) Agitation cultivation under pressure can be conducted under variable conditions, with pressures ranging from normal pressure to 600 kg/cm^2 and temperatures up to 300°C, in a container having a capacity of 530 ml
7) Pressurized cultivation conditions can be observed through an endoscopic camera
8) Activity can be measured within pressurized agitation cultivation vat without reducing pressure
9) Activity of culture fluid can be measured instantaneously

Figure 6. Outline of System for Investigation and Cultivation of Deep-Water Microorganisms, and Research Concerning Their Physiology and Ecology

Key: Under conventional research methods, it has been difficult to maintain original pressure throughout the processes of sample collection and separation and the isolation and cultivation of microorganisms. Instead, decompression and recompression were repeated with each operation. The current objective is to perfect a system whereby research (collection through cultivation) can be conducted while steadily maintaining original pressure levels.

Chemical classification based on DNA base constituents, lipids, isoprenoid quinone, etc., has been found useful in classifying deep- water microorganisms. The relationship between the pressure and cell membrane and enzyme activities has also indicated that the deep-water microorganisms demonstrate unique phenomena, including no loss of activity or change of configuration at high pressures. Systems have also been developed for measuring the bioactive substances produced by deep- water microorganisms which have been isolated and cultivated, and these measurements have been taken. As a result, in the search for substances which would activate or inhibit the multiple functions of human polymorphonuclear leukocytes, 88 strains of bacteria and 36 strains of Actinomyces have been collected and isolated from deep and shallow ocean waters. Strains have also been found which appear to increase the action of microphages against cancer cells.

Although the instances noted above are a very limited sample, significant results have been obtained. Therefore, research results are highly anticipated for next year and thereafter. In particular, in order to obtain a wider diversity of samples, it will be important to study organisms in symbiosis with the higher plants and animals, as well as those obtained directly from seawater or ocean floor sampling.

2. Research Concerning an Explanation of Ocean Plate Formation (Rift Type) in the South Pacific

Most of the earth's geological phenomena are currently being explained within the framework of plate tectonics. The rifts, where ocean plates are being formed, are areas where material and energy from the mantle layer leaks out onto the surface of the earth, and are thus thought to represent the sources of violent volcanic and geothermal activities. A geological, physicochemical, and biological understanding of the actual conditions in the rift system is necessary, not only for an overall understanding of plate tectonics, but also for an understanding of the specialized organisms which live in the vicinity of deep-water geothermal ore deposits and geothermal activity.

Based on these observations, the current research was initiated in 1987 under the supervision of Professor T. Nagumo of Tokyo University, chairman of the Research Promotion Committee, with the first phase scheduled to continue for 3 years and the second phase scheduled to last for an additional 2 years. This research is being implemented in cooperation with France, under a program for international cooperation in research (Starmer Plan) (Table 1).

Table 1. Structure for Implementation of Research Concerning an Explanation of Ocean Plate Formation (Rift Type) in the South Pacific

Research Topic	Organization in Charge
(1) Clarification of rift plate formation process and surrounding environment	
1) Study and research on geological features and structure of the earth's crust	Geological Survey of Japan, Agency of Science and Technology, Ministry of International Trade and Industry
2) Study and research on origin of plate-forming material	
i) Study and research on deposits and stone	Same as above
ii) Physical and chemical study and research on seawater	National Institute for Environmental Studies, Environment Agency
3) Study and research on deep-water microgeological formations	Marine Science and Technology Center, Maritime Safety agency, Ministry of Transport
4) Study and research on ecological systems in the vicinity of rifts	
i) Study and research concerning the mechanisms of chemical synthesis in microorganisms	Tsukuba University
ii) Ecological study and research on large-scale biotic communities	Marine Laboratory, University of Tokyo
(2) Research on plate formation mechanism	Institute for Future Technology
(3) Promotion of research	R&D Office, Science and Technology Promotion Office, Science and Technology Agency

This research is scheduled to begin in 1987, with the firststage lasting for 3 years and the second stage lasting for 2 years. Research will be conducted by means of international cooperation with France.

This research is still in its first phase, but last year and this year the Marine Science and Technology Center ship Kaiyo conducted research on the ocean floor in the vicinity of northern Fuji, at a depth of approximately 1,980 meters, and discovered biotic communities around undersea hotsprings (Figure 7, Photograph 2 [not reproduced]). Details must await further research, but groupings of deep-sea ("hibari") shellfish, blind crabs, and deep-sea ("koshiori") shrimp were found gathered around the hotsprings. The resulting ecosystems appear unique, differing from those which depend on solar energy in that the primary producers in these deep-water ecosystems seem to be microorganisms which carry out chemical synthesis using the methane and hydrogen sulfide emitted from within the earth.

Next year the French diving research ship (Nautil) will join this research. Results of this research, including the gathering of samples, are eagerly awaited.

Conclusion

The ocean is where new land is made (from the ocean plates), and is also said to be the original home of all life on earth. Even though man can reach 98 percent of the ocean floor, the sea is still an unknown world, and will continue to offer surprises.

To increase our understanding of the sea, it is necessary to press on without hesitation. This is the desire of all of us who are involved with the promotion of marine science and technology.

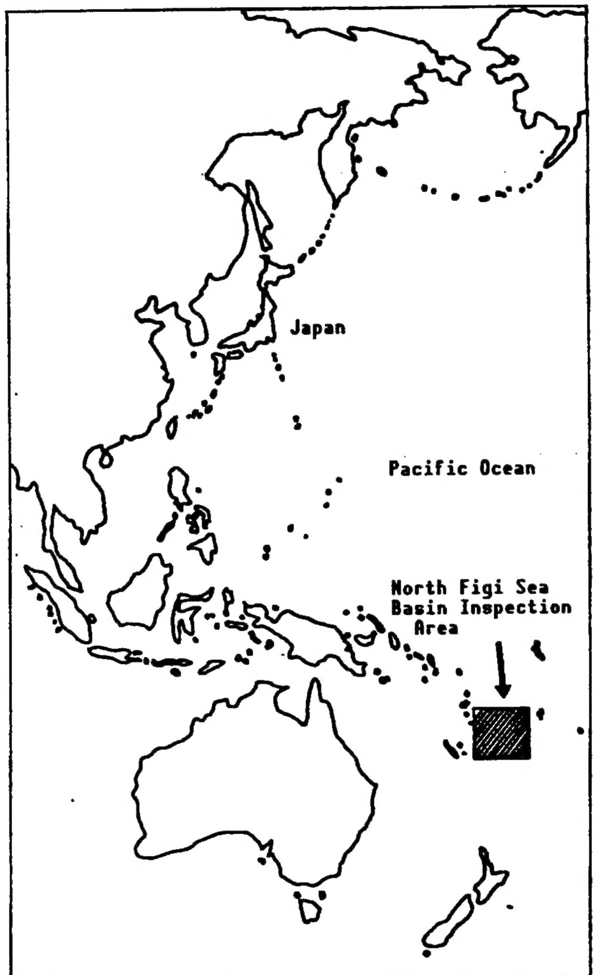


Figure 7. Position of the North Fuji Sea Basin in the South Pacific

Key: Investigations by the Kaiyo, sponsored by the Marine Science and Technology Center, showed biotic communities around underwater hotsprings on the ocean floor in the North Fiji Sea Basin, at a depth of approximately 1980 m.

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